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North Saskatchewan River
Characterization of Water Quality in the Vicinity of Edmonton (1982-83)
Part II

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NORTH SASKATCHEWAN RIVER:
CHARACTERIZATION OF WATER QUALITY
IN THE VICINITY OF EDMONTON (1982-1983)

PART II

ZOOBENTHIC SURVEYS OF SPRING, SUMMER, AND FALL 1982

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January 1986

SUMMARY

A study of the water quality of the North Saskatchewan River as reflected by the zoobenthos or benthic invertebrates was initiated in the spring of 1982. Its primary objectives were the characterization of the river as it passes through the Edmonton area, and the identification of the degree of impact from urban development. Another objective was to evaluate complementary zoobenthic studies as integrators of water quality and as aids to the interpretation of chemical and physical data. Benthic invertebrate samples were collected in spring, summer, and fall 1982 at 11 sites from Devon to Pakan on both left and right banks.

The results of multivariate analyses (cluster and principal component analyses) and an evaluation of commonly used community parameters (total numbers, Shannon-Wiener diversity, distribution of numbers among taxa at each site, and distribution of numbers among sites for each major taxon) led to the identification of three major groups of sites. These groups represent zones of different water quality in the river.

Zone I was a group of sites which were located upstream of major point-source effluents. Benthic invertebrates were virtually unimpacted and the invertebrate assemblage was indicative of river water of high quality. The zoobenthos was characterized by relatively low total numbers and by high values for the Shannon-Wiener diversity. Taxa such as Ephemeroptera, Plecoptera, and Trichoptera, (known to be intolerant of high organic loads) were as important numerically as more tolerant taxa.

Zone II was an impacted group of sites located downstream of the major point-source discharges in the Edmonton area. Total benthic invertebrate numbers were much higher than in Zone I and tolerant taxa were numerically dominant. Diversity index values dropped.

Zone III was a group of sites showing some recovery and situated downstream of Zone II. Total invertebrate numbers remained much higher than in Zone I, but the zoobenthic assemblage of Zone I and Zone III had features in common as shown by similar diversity values and similar distributions of numbers among major taxonomic groups.

Municipal and industrial point-source discharges were responsible for the existence of zones of different water quality in the North Saskatchewan River from Devon to Pakan. The relative length of each zone at different times of the year was influenced by the flow rates and the water temperature regime.

Municipal discharges (wastewater treatment plant effluents, storm and combined sewer effluents) are the main contributors to the nutrient and total organic loads of the North Saskatchewan River. Certain invertebrate taxa responded to these point-source discharges by increasing in numbers. The magnitude and consistency of this type of response was greatest below the Gold Bar Wastewater Treatment Plant. The impact from storm and combined sewer effluents was most evident during summer and fall. During periods of heavy runoff, combined sewers known to discharge a mixture of sewage and surface runoff into the North Saskatchewan River induced a much sharper

increase in invertebrate density than did storm sewers which discharged mainly surface runoff into the river.

Specific impacts of industrial discharges were masked by the enrichment effects of the Gold Bar Wastewater Treatment Plant. There were no consistent indications of an overall toxic effect in the study area delimited by the Devon and Pakan bridges. Enrichment, particularly below Fort Saskatchewan, had a greater impact on benthic invertebrates. However, the purpose of this study was to assess the integrated impact of all effluents on the water quality of a given section of the North Saskatchewan River, not to measure the impact of industrial point-source effluents.

Seasonal differences in water temperatures and flow rates explained the differences in the relative lengths of Zone II and Zone III in spring and fall. Biological and chemical breakdown processes take place more rapidly at higher temperatures, provided that dissolved oxygen levels are adequate. The North Saskatchewan River had satisfactory dissolved oxygen levels throughout the year in 1982, which permitted benthic invertebrates to recover faster below point-source effluents in the fall than in the spring. The faster recovery in the fall of 1982 was undoubtedly related to the scouring or cleansing process which accompanied the unusually high discharge in the spring of that year. Invertebrate data suggested the existence of a cyclic and dynamic pattern whereby the river bed is cleaned by scouring if spring peak discharges are adequate, and gradually enriched and fouled in downstream direction during summer and fall by discharges from the Edmonton urban area.

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ACKNOWLEDGMENTS

The author wishes to acknowledge the help of several individuals in completing Part Two of this report.

Bernard Wright provided field and laboratory assistance; Grant Bodie, David Dowhaniuk, Scott Livingstone, and Martin Soetaert assisted in the field; Marianne Lines provided laboratory assistance; Marianne Klemka and Teresa Richey assisted with proofing. Figures for Part Two of this report were prepared by Terry Zenith and staff, Design and Construction Division. Hal Hamilton provided valuable comments on a first draft. Stewart Anderson critically reviewed and edited the manuscript. I especially thank Lilliane Godin and Gloria de Castro for typing the manuscript.

1.0 INTRODUCTION

This report summarizes the results of a zoobenthic survey which was conducted during the spring, summer, and fall of 1982 in the North Saskatchewan River at eleven locations between and including the Devon and Pakan bridges. This survey comprised Part Two of a broader water quality survey conducted by the Water Quality Control Branch, Alberta Environment, on the North Saskatchewan River in 1982 and 1983. The results of the water chemistry, chlorophyll, and bacteriological studies are presented in Part One.

The principal objectives of the zoobenthic survey were:

1. to provide a spatial and temporal characterization of the North Saskatchewan River zoobenthic community as it reflects river water quality in the vicinity of Edmonton City by assessing bank-to-bank, upstream-downstream, and seasonal differences.
2. to assess the impact of urban development in the Edmonton region on the zoobenthic community of the North Saskatchewan River.
3. to evaluate the zoobenthic survey as a complementary study to the water chemistry survey.

Part Two was undertaken with the expectation that zoobenthic data and physical-chemical data provide converging lines of evidence on water quality and, therefore, that they should complement rather than replace each other. The value of such a complementary approach has been discussed extensively in the literature (e.g. Hynes 1970, Cairns and Dickson 1973). Surveys of chemical and physical variables provide a means of detecting and quantifying a wide range of pollutants in rivers; they also permit the determination of point-sources for these pollutants and provide the basis for enforceable standards. However, water chemistry surveys describe conditions at the time of sampling and, depending on flow regimes, mixing patterns, and type of effluent discharge, the data and their interpretation may not be representative of the nature and extent of pollution. Pollutants which are present at low concentrations or which occur sporadically may remain undetected by standard analytical techniques; such pollutants can have significant impacts on river biological communities, because they are exposed to these substances over an extensive period of time.

Because quality of the water is only fully manifested in relation to living organisms, it is important to monitor the effects of water quality changes on biological communities. Of the total aquatic fauna present in a river, the zoobenthos offers the greatest potential in terms of biomonitoring. Because of the low mobility of most species, the zoobenthos has less ability to escape adverse water quality conditions than fish or plankton. Although zoobenthic taxa may respond to the deterioration of their habitat by drifting, most species are restricted to a given river section by their low mobility potential. Here, they remain exposed to changes in water quality over time and they respond according to their tolerance levels.

The zoobenthic community integrates variations in water quality over an extensive time period prior to sampling and, consequently, can be used successfully to aid in the assessment of water quality. However, the complexity and diversity of interactions of components of biological communities with each other and with their abiotic environment make it difficult to find a fully satisfactory descriptor of water quality in terms of biological parameters*. To date it has not been feasible to set water quality standards in terms of absolute quantitative biological data. Therefore, one of the objectives of Part One of this study (i.e. a comparison of current river water quality with the Alberta Surface Water Quality Objectives**) is not applicable to Part Two, the zoobenthic survey.

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* "parameter" in the sense of Sutcliffe (1979).

** Alberta Environment 1977.

2.0 METHODS

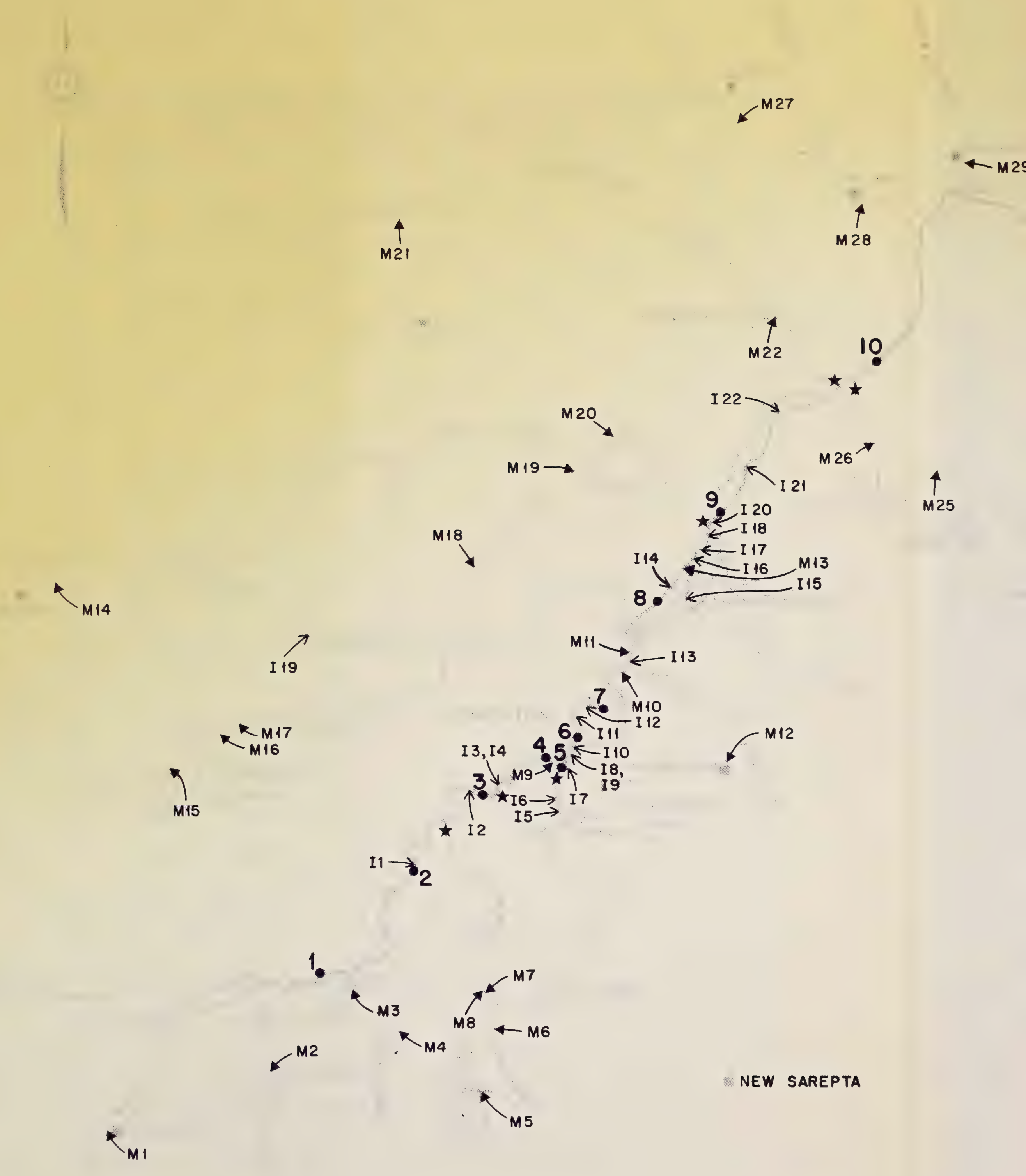
2.1 The Study Area and Study Design

The zoobenthic survey was conducted in the section of the North Saskatchewan River extending from a location near the Highway 60 bridge at Devon to a location downstream of Pakan Bridge at the old river ferry crossing near Victoria Settlement (Fig. 1). The major industrial effluents entering this section of the river are listed in Table 1a; the municipal sewage effluents are listed in Table 1b. Major effluent locations are shown in Figure 1. The main historic, geologic, geographic, and other river basin characteristics and the mixing processes in the study section of the river are described in Part One of this report.

The zoobenthos was sampled three times in the North Saskatchewan River during the open-water season of 1982:

Spring	May 17 to June 3
Summer	August 9 to August 17
Fall	September 23 to October 10

Because of the integrator quality of the zoobenthos and because of the relative longevity of most zoobenthic taxa (several months to two or more years), it was neither necessary nor practical to sample zoobenthos with the same frequency that water samples were taken for chemical analysis.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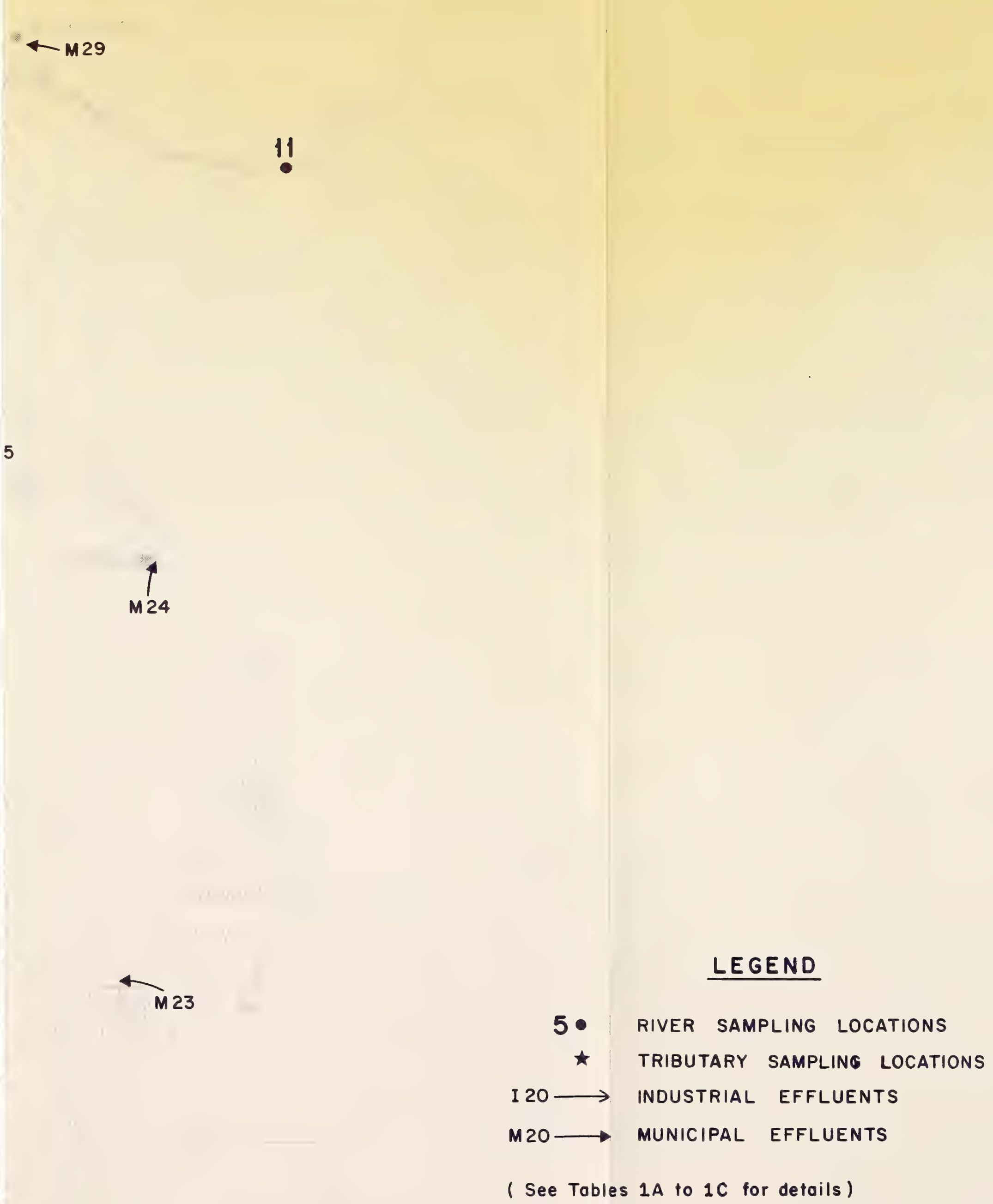
M29
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LEGEND
5 ● RIVER SAMPLING LOCATIONS
★ TRIBUTARY SAMPLING LOCATIONS
I 20 ⟶ INDUSTRIAL EFFLUENTS
M 20 ⟶ MUNICIPAL EFFLUENTS
(See Tables 1A to 1C for details)

Fig. 1. North Saskatchewan River study area.

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TABLE 1a. Major Industrial Effluents Entering the North Saskatchewan River in the Vicinity of Edmonton City, 1982.

I1.	E. L. SMITH WATER TREATMENT PLANT
I2.	UNIVERSITY OF ALBERTA (THERMAL)
I3.	ROSSDALE POWER PLANT
I4.	ROSSDALE WATER TREATMENT PLANT
I5.	STELCO
I6.	C.I.L.
I7.	IMPERIAL OIL REFINERY
I8.	SYNCRUDE RESEARCH
I9.	TEXACO REFINERY
I10.	GULF REFINERY
I11.	CELANESE CANADA, UNIROYAL, FIBERGLASS
I12.	CLOVERBAR POWER PLANT
I13.	ALBERTA CONCRETE, NESBIT
I14.	ALBERTA FOOD PRODUCTS
I15.	MANVILLE CANADA INC.
I16.	SHERRITT GORDON
I17.	UNION CARBIDE
I18.	DOW CHEMICAL
I19.	ALBERTA CONCRETE, VILLENEUVE
I20.	DIAMOND SHAMROCK
I21.	SHELL REFINERY, SCOTFORD
I22.	ESSO CHEMICALS, REDWATER

TABLE 1b. Municipal Sewage Effluents* Entering the North Saskatchewan River directly or indirectly in the Vicinity of Edmonton City, 1982.

M1. THORSBY
M2. CALMAR
M3. DEVON SEWAGE TREATMENT PLANT
M4. INTERNATIONAL AIRPORT
M5. LEDUC
M6. NEW SAREPTA
M7. BEAUMONT
M8. NISKU
M9. GOLD BAR WASTEWATER TREATMENT PLANT (GBWTP), EDMONTON
M10. BREMNER SEWAGE LAGOONS
M11. ST. ALBERT SEWAGE LAGOONS
M12. ARDROSSAN
M13. FORT SASKATCHEWAN
M14. ONOWAY
M15. STONY PLAIN
M16. PARKLAND VILLAGE
M17. SPRUCE GROVE
M18. MORINVILLE
M19. BON ACCORD
M20. GIBBONS
M21. LEGAL
M22. REDWATER
M23. TOFIELD
M24. CHIPMAN
M25. LAMONT
M26. BRUDERHEIM
M27. THORHILD
M28. RADWAY
M29. WASKATENAU

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* Since this study was completed, the Edmonton Regional Wastewater Treatment Plant has become operative, combining some of the above treatment facilities. These changes are described in greater detail Part One of this report.

TABLE 1c. Regular Zoobenthos Sampling Locations, North Saskatchewan River, 1982.

Location Number	Location Name	Relative River Kilometres	Location Description	Selection Criteria
1.	DEVON	0	Near Devon Bridge, Highway 60	Control location (background conditions.
2.	E. L. SMITH	24	Immediately upstream E.L. Smith water treatment plant	To determine impacts from Devon municipal effluent on water supply
3.	ROSSDALE	40	100 m downstream of 105th St. Bridge-Rossdale	To determine impacts from large separate storm sewers on water quality for Rossdale Water Treatment Plant
4.	50TH STREET FOOTBRIDGE	51	100 m upstream of 50th St. Footbridge	To identify impacts from large combined storm sewers before Gold Bar Wastewater Treatment Plant
5.	RUNDLE FOOTBRIDGE	52	100 m downstream of Rundle Park Footbridge	To identify impacts from Gold Bar Wastewater Treatment Plant prior to industrial discharges
6.	BEVERLY BRIDGE	55	200 m downstream Beverly Railway Bridge	To incorporate effects of industrial - part refinery discharges
7.	CLOVER BAR	61	4 km downstream of Celanese; downstream of Clover Bar	To incorporates all municipal and industrial effluents from Edmonton
8.	FORT SASKATCHEWAN	79	200 m upstream Fort Saskatchewan Railway Bridge	Downstream of St. Albert and Bremner lagoons
9.	STURGEON	89	Downstream of confluence with Sturgeon River	To include effects of Fort Saskatchewan industrial and municipal effluents
10.	VINCA	112	500 m downstream of Vinca Bridge	To reflect all major inputs; also robot monitor location
11.	PAKAN	163	10 km downstream of Pakan Bridge	Location reflecting complete mixing in the river; also near a routine monitoring site

The eleven regular sampling locations for 1982 are listed in Table 1c and are shown in Figure 1. Zoobenthos sampling sites were virtually the same as left-bank and right-bank water chemistry sampling sites in 1982.

The farthest upstream and downstream locations were chosen to represent relatively unimpacted (control) sites, and sites within the recovery zone, respectively. The other nine locations were selected on the basis of their representativeness and value in identifying potential impacts from certain known discharges. At each sampling location, two sampling sites were established, one near the right-bank and one near the left-bank.

Although there are dams, agricultural and oilfield developments, and some population centres (Rocky Mountain House and several smaller centres) upstream of Devon, the NSR at the Devon bridge is considered relatively unimpacted by domestic and industrial waste effluents (unpublished data, Alberta Environment). The first sampling location is upstream of the Devon Sewage Treatment Plant, at the site of an Alberta Environment River Water Quality Monitoring Network monitor.

The mixing studies reviewed in Section 3.0, Part One of this report indicated incomplete mixing as far downstream as Vinca bridge on Highway 38. However, it is assumed that mixing is complete most or all of the year at Pakan Bridge, another routine station of the River Water Quality Monitoring Network. The site was therefore chosen as the lower sampling location.

2.2 Field Methods and Site Selection

Under natural conditions (i.e. absence of pollution) in any section of a river, localized differences in faunal composition are mainly due to variations in habitat characteristics. Current velocity and substrate type are often the most important in this regard (Hynes 1972). All sites selected for benthic invertebrate sampling were riffles in order to provide a high similarity in substrate type among sites. An attempt was made to fix precise sampling location so that successive sampling was done in the same type of substrate. The substrate of all sites except the Sturgeon left-bank site, which was boulder and cobble, was medium to coarse pebble mixed with sand and silt (terminology according to Cummins, 1962). There was less silt at most upstream sites, such as Devon, than at sites downstream of Edmonton, but there was more sand at upstream sites than at downstream sites. The variation in amount of silt from site-to-site was greater during the spring sampling than during the fall sampling; during the summer all sites had a similar amount of silt.

At least 3 measurements of current velocity were made at each site using a Gurley current meter.

At each site, 5 Neill cylinder samples (Neill 1938), representing a sampling area of 0.1 m^2, were collected and filtered through a collecting net with mesh aperture of 210 µm. Care was taken to press the cylinder securely into the substrate to prevent the loss of specimens through gaps between the sampler and the substrate.

Larger stones were individually cleaned by gentle scrubbing and rinsing in the cylinder. A narrow shovel was used to disturb the substrate for approximately one minute. Samples were preserved in 4% formaldehyde immediately after collection.

2.3 Laboratory Methods

Samples collected in the field were stained with Rose Bengal before being sorted and enumerated in the laboratory under a dissecting microscope. Mason and Yevich (1967) have shown that the efficiency with which zoobenthic specimens are separated from the detritus fraction is greater in samples which have been stained, because animals are more easily distinguished from algae and detritus. Sorting under a dissecting microscope may be more time consuming than sorting in the field, but it is a more accurate method for the processing of river benthos.

Invertebrates were identified according to Bauman *et al*. (1977), Clarke (1973), Edmunds *et al*. (1976), Merritt and Cummins (1979), Pennak (1953), Usinger (1956), and Wiggins (1977).

2.4 Data Analysis

The Shannon-Wiener Diversity Index is one of the most widely used mathematical expressions of abundance and diversity in biological systems, although many other expressions have also been proposed to summarize extensive data sets in concise and meaningful terms (e.g.

Shannon and Weaver 1949, Simpson 1949, King and Ball 1964, Cairns et al. 1968, Chutter 1972, Hilsenhoff 1977, Armitage et al. 1983). One of the major purposes of these expressions is to relate their calculated values to environmental conditions, such as levels of pollution, as a means of appraising the degree or extent of environmental impact (Hellawell 1977, Godfrey 1978, Perkins 1983). In this report, the Shannon-Wiener diversity index (H') was used and calculated according to the following formula:

$$H' = -\sum_{i=1}^{n} p_i \ln p_i$$

where $p_i = n_i/N$
n_i = numbers in taxon i
N = total numbers
n = number to taxa

The Shannon-Wiener diversity index or H' is a quantitative measure of diversity which takes numbers per taxon into account, but is not affected by the actual species composition or assigned tolerance levels for individual species as are most "biotic indices" (e.g. Hilsenhoff 1977, Rooke and Mackie 1982, Armitage et al. 1983). The usefulness of H' in assessing the impact of pollution is based on the assumption that pollution-related factors affect total community structure. Unaffected communities are, in general, characterized by an even distribution of numbers per species (i.e. many species with few individuals per species), whereas affected communities tend to have skewed distributions (i.e. high densities for a few species; low numbers for the remaining species). Generally, H' has the highest values in unpolluted habitats, and decreases as the degree of pollution increases (Cairns et al. 1972, Hughes 1975). In unpolluted waters, the index ranges from 3.0 to 4.0; in stressed communities, it may drop below 1.5 (Wilhm 1970).

Cook (1976) has suggested that H' is sensitive to impacts along the entire pollution spectrum from unpolluted to heavily polluted. Although H' has been used successfully as an indicator of pollution impact in numerous studies, one should be cautious in the interpretation of diversity values (Godfrey 1978, Hughes 1978, Murphy 1978, Cook 1976). For example, many studies have shown that H' is inversely correlated with pollution, but there are exceptions to this relationship (Harrel and Doris 1968). Trends in H' values along a gradient might be meaningful, but it would be spurious to elaborate on slight differences in H' values which could be due to chance (Cook 1976). Hughes (1975) has shown that factors such as sampling method, area sampled, time of year, and taxonomic level of identification all influence the value of H'. Therefore, comparisons between diversity values are not legitimate when sampling and processing techniques are inconsistent or when samples are compared for different seasons.

2.4.1 Cluster Analysis and Principal Component Analysis

Two multivariate techniques, cluster analysis and principal component analysis, were used in the analysis of zoobenthic data. Both analyses provide a means of comparing samples using all numerical abundance data for each taxon. Some theoretical considerations and practical applications of these two techniques have been discussed by Gauch and Whittaker (1972), Sinhai (1977), Sprules (1977) and Green (1979). Cluster analysis and principal component analysis were performed with the aid of the CLUSTAN-Package (Wishart 1978).

Cluster analysis is a technique whereby the data are analyzed by site and are grouped according to similarities among the zoobenthic species (i.e., qualitatively and quantitatively). The similarity index used in the present analysis was the squared euclidean distance. A variety of techniques can be applied to the resulting similarity matrix for the fusion of similar clusters. The Ward (1963) method was used here. Results were obtained graphically in the form of a dendrogram. Site data sets with similar zoobenthic associations clustered together; the differences in similarity coefficients between clusters at their fusion points was used as a relative measure of the degree of similarity (or dissimilarity) between clusters.

The description by Green (1979, p. 82) shows how principal component analysis converts the "m samples by p variables" data set to a "p-by-p" covariance or correlation matrix. The roots and vectors (called eigenvalues and eigenvectors) of this p-by-p matrix are then found; they correspond respectively to the variance associated with each principal component and to the principal component coefficients b_{i1} in the following function:

$$Y_i = b_{i1} X_1 + b_{i2} X_{2+} \ldots + b_{ip} X_p.$$

Principal component analysis transforms observations on a set of p variables $X_{j=1,p}$ to observations on a new set of quantitative variables $Y_{j=1,p}$ where the new set has the following properties (see Marriott 1974, cited by Green 1979, p. 81):

1. Each new variable Y_i is a linear additive function of the old variables:

   $Y_i = b_{i1} X_1 + b_{i2} X_2 + \dots + b_{ip} X_p$

2. The first new variable extracted (Y_1) is the first principal component and accounts for the largest possible amount of variation in the data set.

3. Each additional new variable accounts for the largest possible amount of remaining variation, independent of the previously derived principal components. Therefore, the new variables Y_i will be uncorrelated, unlike the original variables X_j. They will also tend to be more normally distributed.

2.4.2 One-Way Analysis of Variance

A one-way analysis of variance (ANOVA) was used to compare the means for selected benthic parameters from site groups (clusters) which were identified by multivariate analysis. The test was performed on the following parameters: numbers of Nematoda, Oligochaeta, Ephemeroptera, Plecoptera, Trichoptera, Chironomidae; total invertebrate numbers; total number of invertebrate taxa; Shannon-Wiener diversity.

For each parameter, the data set was tested for normality with the Kolmogorov-Smirnov test (Seigel 1956; Hull and Nie 1981). If a normal distribution was rejected ($p>0.05$), data were transformed to $\ln(x+1)$ (Elliott 1977). The Kolmogorov-Smirnov test on the transformed data showed that the normality was increased satisfactorily in all cases. Normally distributed data were analyzed with a one-way ANOVA to determine the significance of differences between sites for each parameter (Sokal and Rohlf 1969, Elliott 1977, Nie _et_ _al_. 1975). If such differences were significant, a Student-Newman-Keuls test (Sokal and Rohlf 1969, Nie _et_ _al_. 1975) was performed to determine whether the means for site groups were significantly different.

3.0 RESULTS

3.1 General Description of the Invertebrate Community

The benthic invertebrate taxa which were collected in the North Saskatchewan River in this study are listed in Table 2. A total of 107 zoobenthic taxa was recorded for the overall study, with 77, 75 and 94 taxa for the spring, summer, and fall samplings, respectively. Table 2 also gives a general indication of the abundance of the various taxa in the three sample sets. The raw benthic invertebrate data sets for the spring, summer, and fall surveys are included in Part Three. For the convenience of readers who may not be familiar with both the scientific and common names for some of the taxonomic groups discussed in this report, a summary is given in Appendix I.

The major taxonomic groups identified in the benthos of the North Saskatchewan River were Chironomidae (particularly Chironomini and Orthocladiinae), Oligochaeta (mostly Naididae and Tubificidae), Nematoda, Ephemeroptera, Trichoptera, and Plecoptera. Except for the mollusk Ferrissia, which was fairly abundant during summer and fall, the remaining taxa (i.e., Turbellaria, Hirudinea, Collembola, Odanata, Lepidoptera, Arachnida, miscellaneous Diptera, and miscellaneous mollusks) were generally of minor numerical importance.

Ephemerella and Baetis were the dominant mayflies in spring samples, but Tricorythodes and Heptagenia were more important in summer and fall.

TABLE 2 List of Invertebrate Taxa found in samples from the Spring, Summer and Fall Survey.

	SPRING	SUMMER	FALL
Coelenterata	x	x	x
Nematoda			
Mermithoidea	xx	xx	xx
Unid. Nematoda	xx	xx	xx
Turbellaria	x	x	x
Acanthocephala			
Neoechynorhynchus	x	–	–
Cestoda			
Caryophillidae	x	–	–
Oligochaeta			
Tubificidae	xx	xx	xx
Naididae	xx	xx	xxx
Enchytraeidae	x	x	x
Lumbricidae	x	–	–
Hirudinea			
– *Eropbdella punctata*	x	x	x
– *Glossiphonia complanata*	x	–	x
– *Helobdella stagnalis*	–	x	–
– *Nephelopsis obsura*	x	–	–
Amphipoda			
– *Gammarus lacustris*	x	–	x
– *Hyalella azteca*	x	x	x
Copepoda			
– Cyclopoida	x	x	xx
– Calanoida	x	x	x
– Harpacticoida	x	x	x
Cladocera			
– *Ilyocryptus sordidus*	–	–	x
– Misc. (e.g. *Daphnia* sp., *Bosmina* sp, *Ceriodaphnia* sp., *Acroperus harpae*, *Pleuroxus procurvus*)	x	x	x
Ostracoda			
Rotifera Misc. (*Lecane monostyla*, *Asplanchna* sp., *Brachionus* spp.)	x	x	x
Ephemeroptera			
Ameletus	–	–	x
Baetis	xx	x	xx
Caenis	x	x	x
Centroptilum	–	x	x
Ephemera	x	x	x
Ephemeridae	–	x	–
Ephemerella	xx	x	x

TABLE 2 List of Invertebrate Taxa found in samples from the Spring, Summer and Fall Survey Cont'd.

	SPRING	SUMMER	FALL
Heptagenia	x	xx	xx
Heptageniidae	x	x	xx
Hexagenia	x	-	x
Lepthophlebia	-	-	x
Paraleptophlebia	-	x	x
Parameletus	-	-	x
Pseudocleon	-	x	x
Rhithrogena	x	x	x
Stenonema	-	x	x
Tricorythodes	x	xx	xx
Unid. Nymphules	x	xx	xx
Trichoptera			
Arctopsyche	x	x	x
Brachycentrus	x	x	x
Ceraclea	x	x	x
Cheumatopsyche	xx	xx	xx
Glososoma	x	x	x
Hydropsyche	xx	xx	xx
Hydropsychidae	x	xx	xx
Hydroptila	x	x	
Lepidostoma	x		
Leptoceridae	x	x	x
Mayatrichia	-	x	x
Neotrichia	-	x	x
Neureclipsis	x	-	x
Oecetis	x	x	x
Onocosmoecus	x	-	-
Polycentropus	-	-	x
Psychomyia	x	x	xx
Plecoptera			
Acroneuria	x	x	
Alloperla	x	x	x
Capniidae	-	-	x
Chloroperlidae	xx	x	xx
Isogenus	x	x	x
Isoperla	x	x	x
Perlidae	x	x	
Perlodidae	xx	x	xx
Pteronorcys	x	-	-
Taeniopteryx	x	-	x
Unid. Plecoptera	xx	x	xx
Collembola	x	x	x

TABLE 2 List of Invertebrate Taxa found in samples from the Spring, Summer and Fall Survey Cont'd.

	SPRING	SUMMER	FALL
Odonata			
- Aeshna	-	-	x
- Gomphus	x	-	-
- Ophiogomphus	x	x	x
Lepidoptera (Noctuidae?)	x	-	-
Corixidae			
Callicorixa audeni	x	x	xxx
Sigara spp (e.g. S. lineata, S. bilineata)	-	x	x
Hesperocorixa laevigata	-	-	x
H. atopodonta	-	-	x
Notonectidae			
Notonecta undulata	-	-	x
Coleoptera			
Elmidae	x	x	x
Dytiscidae	-	x	x
Chrysomelidae	x	-	-
Haliplidae	-	x	-
Diptera			
Chironomidae			
- Chironomini	xx	xx	xx
- Tanytarsini	x	x	x
- Orthocladiinae	xxx	xxx	xxx
- Tanypodiinae	x	x	x
- pupae	x	x	x
Ceratopogonidae	x	x	x
Tipulidae			
- Erioptera	-	-	x
- Hexatoma	x	x	x
- Anotocha	-	x	x
- Limnophila	-	x	x
- Dicranota	-	x	-
Ephydridae	-	-	x
Chaoboridae			
- Chaoborus	-	x	x
Tabanidae			
- Tabanus	x	-	x
Rhagionidae			
- Atherix	-	-	x
Empididae	x	x	x
Dolichopodidae	x	x	x

TABLE 2 List of Invertebrate Taxa found in samples from the Spring, Summer and Fall Survey Cont'd.

	SPRING	SUMMER	FALL
Simuliidae			
- *Simulium arcticum*	x	x	x
Tanyderidae	x	–	–
Misc. Adult Diptera	–	x	x
Aranea			
Acari	x	x	x
Aranea	x	x	x
Mollusca			
Physidae	x	x	x
Lymnaeidae	x	x	x
Planorbidae	x	–	x
Sphaeriidae			
- *Pisidium*	x	x	x
- *Sphaerium*	x	x	x
Ancylidae			
- *Ferrissia*	x	xx	xx

–	absent (from all sites and samples)
x	sporadic occurrence (occasionally found in certain sites, numbers are usually low)
xx	common (found in most sites, relatively abundant)
xxx	very common (found in virtually all sites and often very abundant)

Caddisflies of the family Hydropsychidae, especially Hydropsyche and Cheumatopsyche, represented the major fraction of the total zoobenthos biomass at Vinca Bridge and Pakan Bridge. Psychomyia and Glossosoma, also common caddisflies in the North Saskatchewan River, were usually less abundant than the two genera noted above.

Perlodidae and Chloroperlidae were the most commonly occurring stonefly families. Most Plecoptera nymphs designated as "unidentified" were members of one of these two families.

A number of taxa, which are not true components of the river benthos, which were present in the samples apparently incidentally rather than as a result of water quality, or which are uncommonly recorded in benthic surveys, occurred in the North Saskatchewan River samples. Abundance data for these taxa have not been included with the raw data in Part Three of this report. The occurrence of these taxa in the samples is discussed here briefly.

In the fall, very high numbers of Corixidae (i.e., estimated as high as 10,000 specimens per sample and consisting mostly of Callicorixa audeni, Sigara lineata and S. bilineata) were present in right-bank samples from E. L. Smith. Somewhat lower numbers were present in left-bank samples from E. L. Smith as well as in samples from both banks at Pakan Bridge. Their presence in the samples was incidental rather than influenced by water quality and the huge population densities would have biased the results. Therefore, corixid numbers were excluded from the data analysis.

Amphipoda (*Hyalella azteca* and *Gammarus lacustris*) were found only in samples from the left-bank site at Sturgeon, the first site downstream of the confluence of the Sturgeon River with the North Saskatchewan River. Because the specimens were believed to have come from the tributary, occurrence data were excluded from the North Saskatchewan River data analysis.

Planktonic taxa such as calanoid and cyclopoid copepods, cladocera (e.g., *Daphnia* spp., *Bosmina longirostris*, *Ceriodaphnia* spp., *Acroperus harpae*, and *Pleuroxus procurvus*), and rotifera (e.g., *Lecane* spp., *Brachionus* spp., *Asplanchna* sp.) occurred in most samples. Zooplankton, normally part of the lentic communities of lakes ponds, and backwaters, can be carried from these standing waters into rivers, where their recurrence is considered incidental (Hynes 1972, Winner 1975). Because of the uncertainty of origin of North Saskatchewan River zooplankton, these data were omitted from further analysis.

A few taxa were encountered in only one or very few samples. These sporadic occurrences were not meaningful in terms of overall water quality assessment, but were of interest from a general point of view. *Ilyocryptus sordidus*, a truly benthic cladoceran, possesses red blood pigment and is particularly well adapted to an existence in muddy substrates; a few specimens were collected at Sturgeon, downstream of the confluence of the Sturgeon River with the North Saskatchewan River. Harpacticoida, copepods with benthic habits, occurred sporadically. A few taxa from the phyla Gastrotricha and Tardigrada were recorded.

Two specimens of the parasite Neoechynorhynchus, a member of the phylum Acanthocephala (identification, Dr. D.R. Mudry), were found in samples from Clover Bar and Sturgeon. These Acanthocephalans parasitize suckers and have arthropods (such as amphipods, ostracods, copepods, insect nymphs) as intermediate hosts. One specimen of a cestode belonging to the family Caryophillidae and having tubificids as the intermediate host (Mudry and Arai 1973) was found at Sturgeon. These parasites are rarely found free in the benthos, and their occurrence there is incidental.

3.2 Community Descriptors

The benthic invertebrate fauna of the North Saskatchewan River is diverse and rich. Numerical data which describe the various taxa from all sites sampled in the three seasons are complex. Although much information can be gathered from the analysis of frequency tables for individual taxa, the sheer volume of collected data makes this approach inefficient even when some non-benthic or other incidental species occurrences were eliminated from the data set. Instead, commonly used community parameters such as total number of taxa, total number of specimens per sample, total number of specimens per major taxon, and diversity were used to describe major community changes. Cluster analysis and principal component analysis permitted the grouping of sites with similar invertebrate communities. Additionally, principal component analysis offered an objective way of determining which taxa explain most of the variance in the data sets.

Tables 3 to 5 summarize means and standard errors for the main zoobenthic parameters (i.e., major taxonomic groups, total invertebrate density, Shannon-Wiener diversity, and total number of invertebrate taxa) in the three surveys. The first three parameters were useful descriptors of major trends in the zoobenthic community of the North Saskatchewan River between Devon and Pakan Bridge. There was a trend toward fewer taxa from Rossdale to Sturgeon, particularly at the right-bank site at Rundle Footbridge. However, the trend was inconsistent and its significance is unclear.

3.2.1 Total Numbers

The average total numbers per site for left-bank and right-bank sites in spring, summer, and fall are shown in Figures 2 to 7 and Tables 3 to 5. Total numbers showed a clear pattern in the river between Devon and Pakan Bridge. They were low for right-bank sites upstream of Edmonton and rarely exceeded 200 individuals per sample. A slight increase in numbers occurred at Rossdale (spring, fall), but the increase became more evident at 50th Street Footbridge (summer, fall). In all three seasonal data sets, the Rundle Footbridge right-bank site showed the most dramatic increase in density. At this site, numbers were one to two orders of magnitude higher than at corresponding upstream sites. It was also at the Rundle Footbridge right-bank site that the highest densities per sample were reported for the entire survey: an average of 26,861

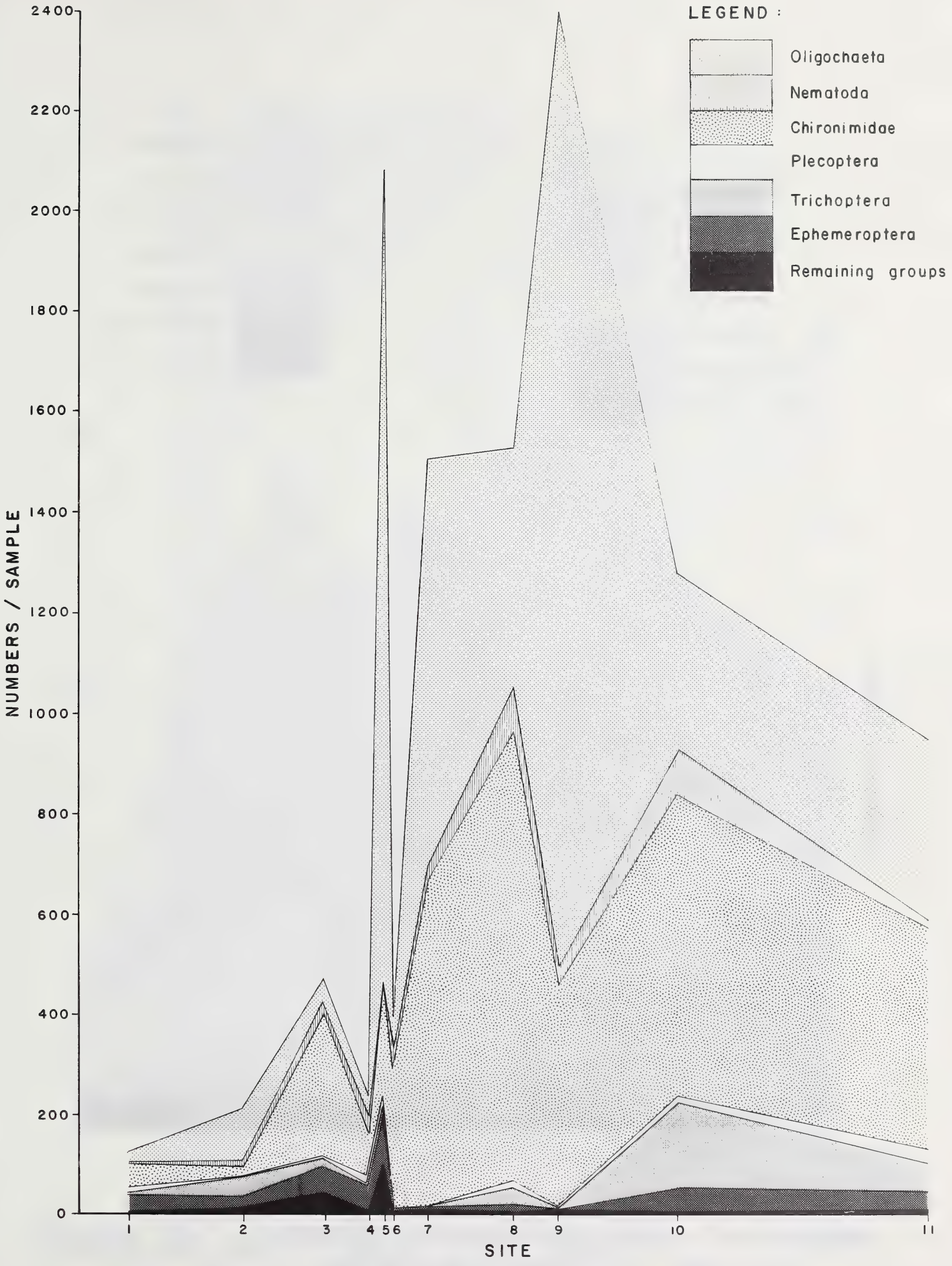

FIGURE 2 . SPRING RIGHT BANK : Total invertebrate density and density of major taxa .
Refer to Table 1c for site labels.

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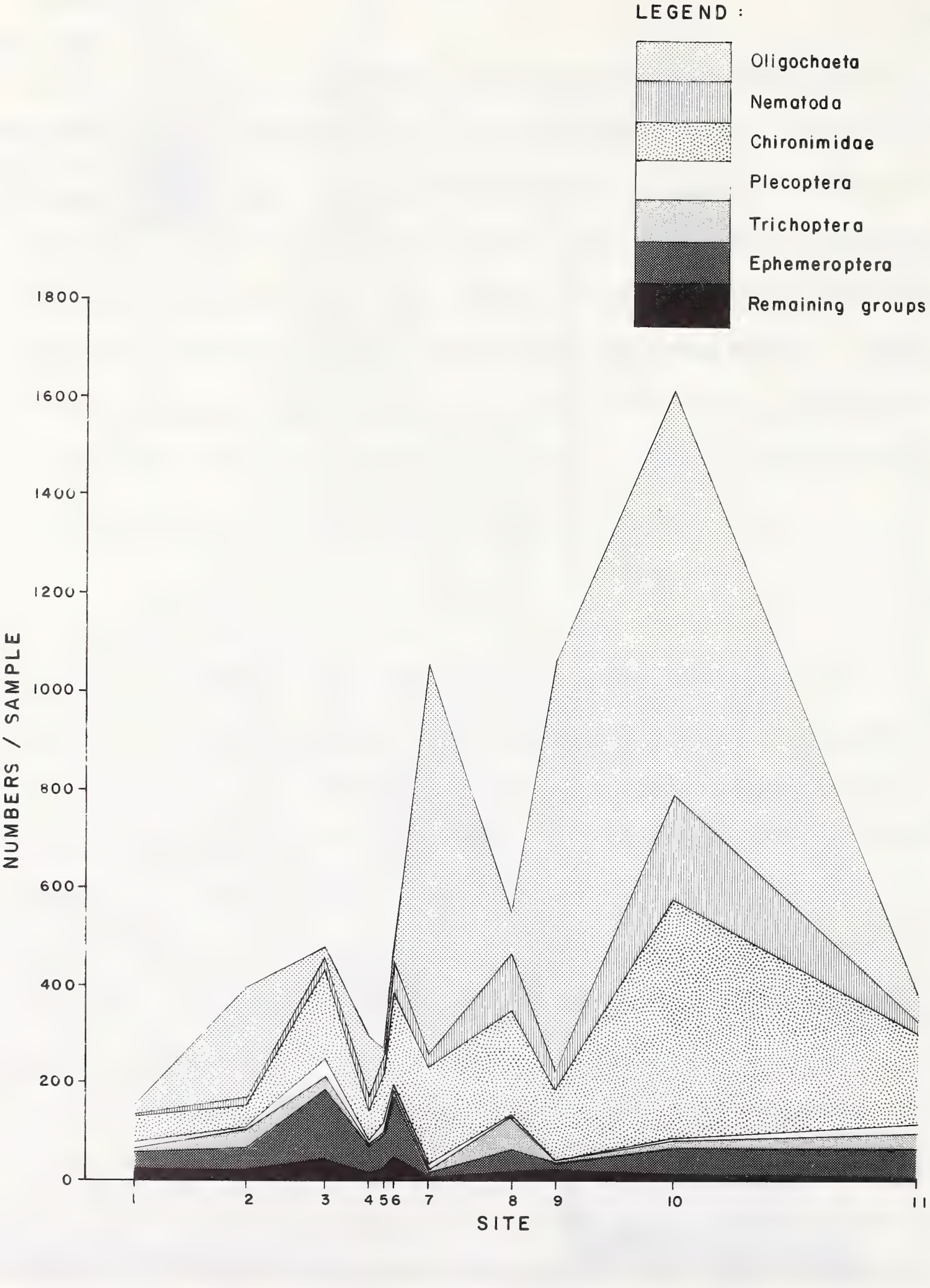

FIGURE 3 . SPRING LEFT BANK : Total invertebrate density and density of major taxa. Refer to Table 1c for site labels.

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Water Quality Control Branch

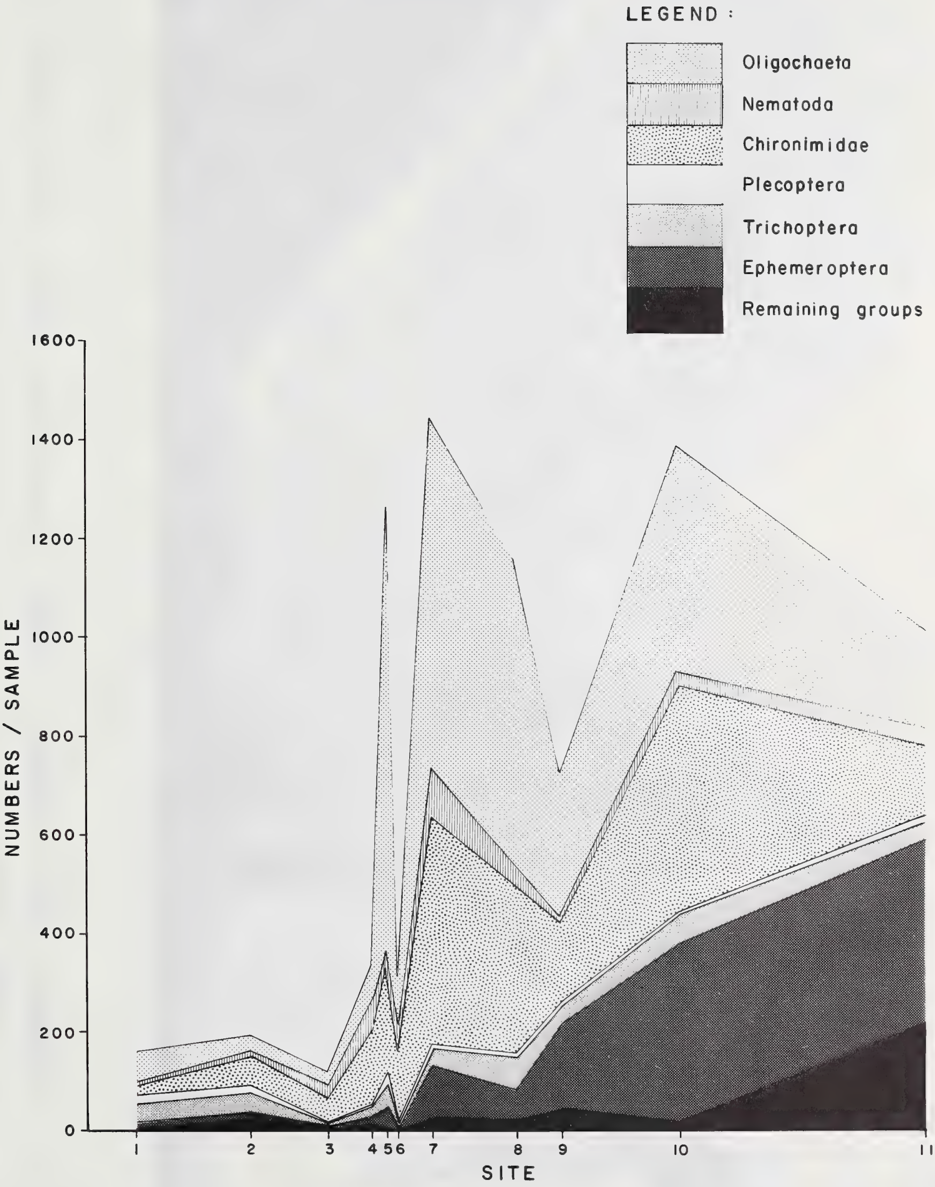

FIGURE 4 . SUMMER RIGHT BANK : Total invertebrate density and density of major taxa.
Refer to Table 1c for site labels.

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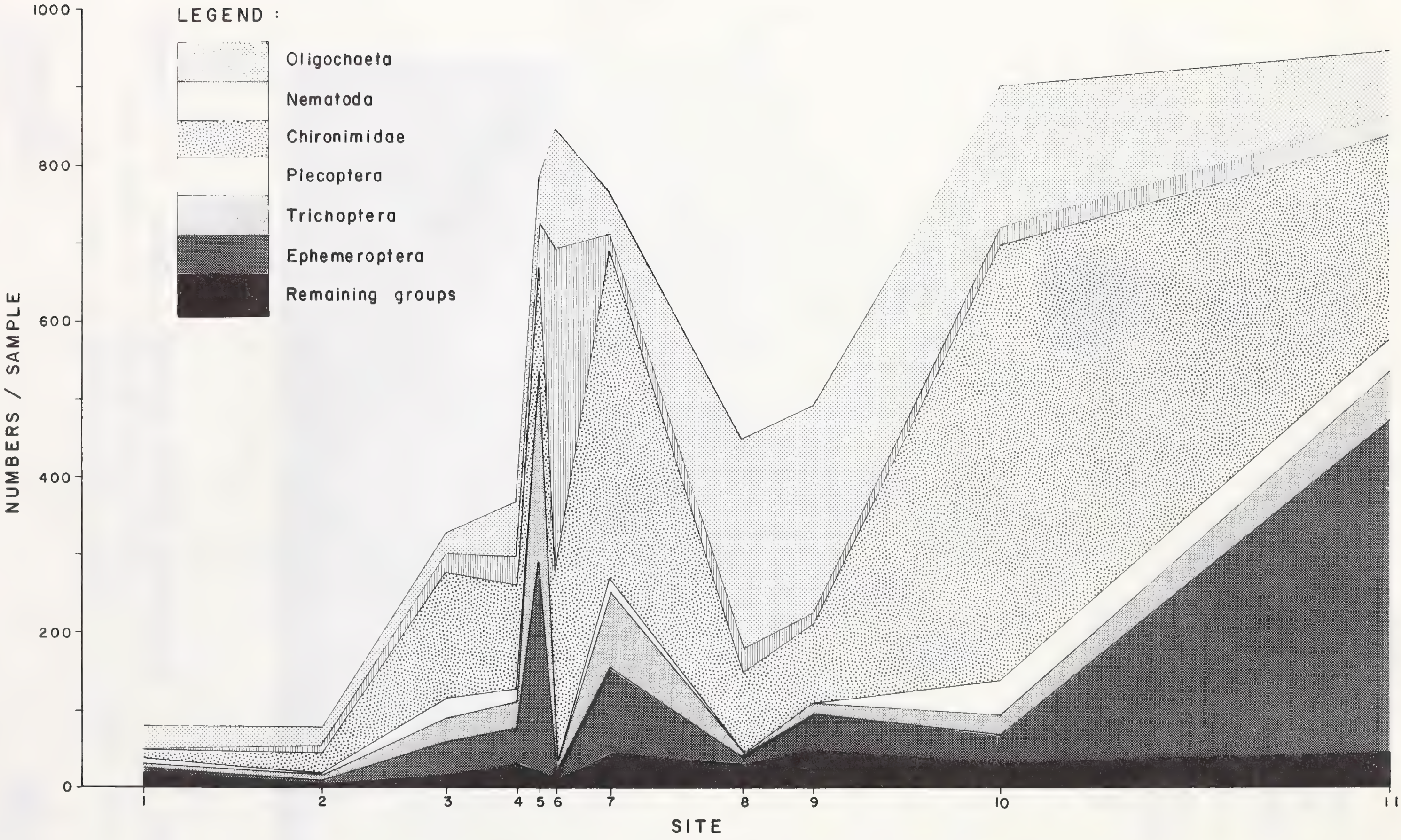

FIGURE 5 . SUMMER LEFT BANK : Total invertebrate density and density of major taxa.
Refer to Table 1c for site labels.

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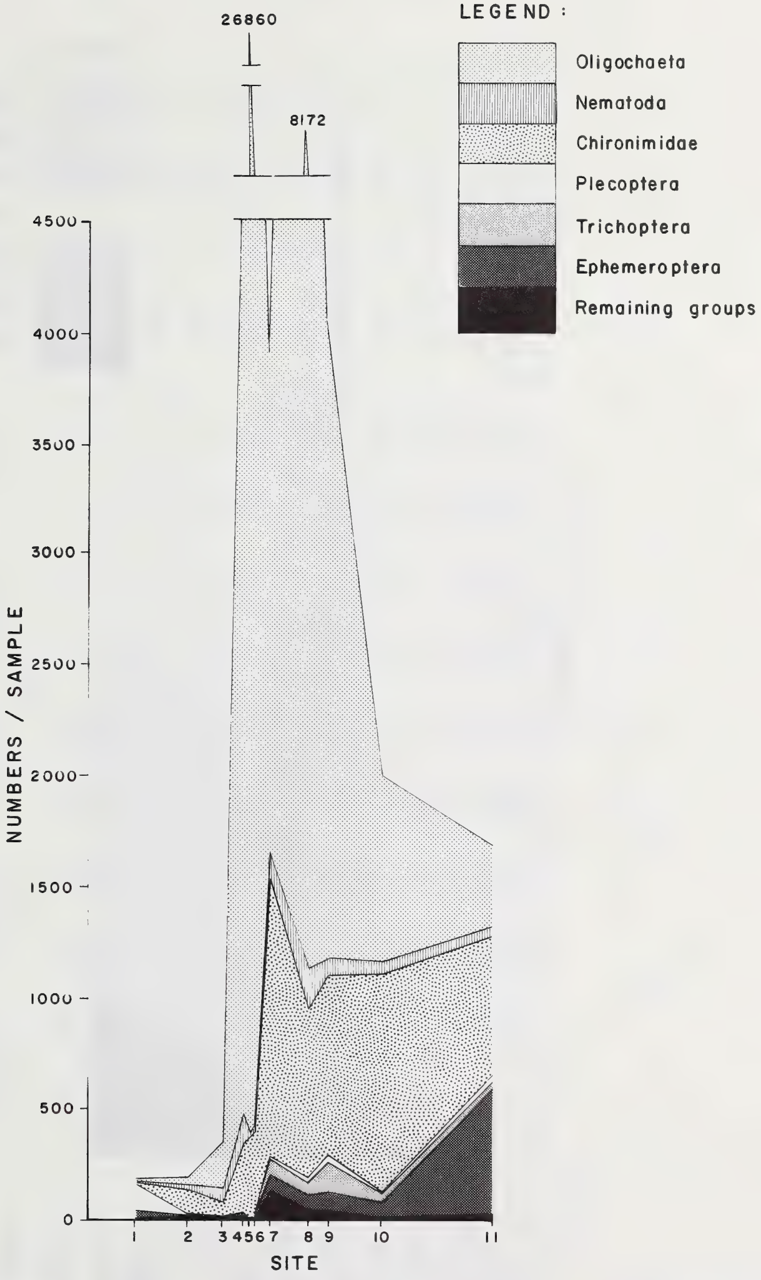

FIGURE 6 . FALL RIGHT BANK : Total invertebrate density and density of major taxa.
Refer to Table 1c for site labels.

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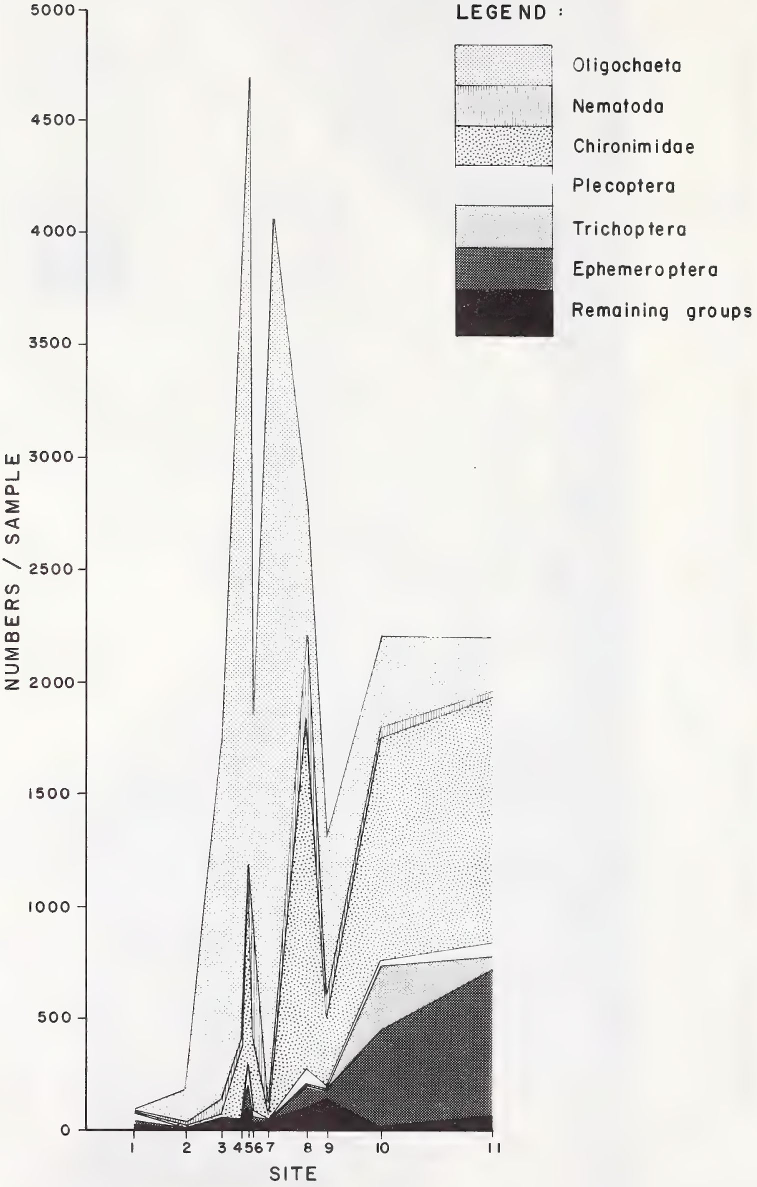

FIGURE 7 . FALL LEFT BANK : Total invertebrate density and density of major taxa. Refer to Table 1c for site labels

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Table 3. Spring 1982, mean and standard error of major zoobenthic parameters

	Ephemeroptera		Trichoptera		Plecoptera		Nematoda		Oligochaeta		Chironomidae		Total Numbers	
	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE
Devon R*	33.2	6.1	3.2	1.0	8.8	1.3	3.2	1.2	20.6	10.7	49.4	7.7	124.4	19.4
Devon L**	38.2	5.9	8.0	2.3	10.0	3.5	3.8	1.5	14.8	1.5	52.0	6.5	150.2	11.7
E.L. Smith R	26.6	4.4	35.6	4.5	2.0	.8	12.4	1.9	103.2	15.6	18.2	2.6	213.8	28.2
E.L. Smith L	46.8	8.4	33.0	11.2	3.6	1.0	12.4	5.3	229.2	27.6	44.2	2.8	391.6	41.9
Rossdale R	53.0	8.4	13.6	3.3	6.2	1.9	35.0	4.6	44.6	8.2	280.6	20.8	477.8	25.2
Rossdale L	141.2	39.7	25.2	7.1	44.6	14.7	23.8	8.4	36.6	12.3	199.8	44.5	478.6	117.7
50th Street R	55.4	11.2	6.8	2.2	11.2	3.1	34.6	9.3	32.0	5.2	85.0	11.2	233.8	25.3
50th Street L	53.6	13.7	4.0	1.8	2.3	1.1	32.8	4.9	121.4	17.3	61.2	5.5	292.4	28.2
Rundle R	108.8	20.8	12.8	5.0	21.6	8.6	5.6	3.5	1622.8	256.4	218.4	14.2	2078.8	270.9
Rundle L	67.0	13.2	2.0	.5	19.4	3.7	40.4	7.5	9.4	2.2	100.2	20.6	264.4	30.9
Beverly Bridge R	6.0	1.6	1.0	.6	1.0	.8	28.2	1.3	54.2	8.1	295.4	17.6	392.6	21.0
Beverly Bridge L	124.2	19.5	11.4	1.9	15.0	2.7	60.0	15.2	25.6	8.2	188.8	37.2	470.2	77.2
Cloverdale R	9.8	2.7	.4	.4	.2	.2	34.0	8.3	796.8	198.0	651.0	118.7	1503.8	250.9
Cloverdale L	11.2	4.9	.6	.4	3.4	1.4	28.2	13.8	802.0	199.6	201.4	31.9	1054.0	216.8
Ft. Sask. R.	18.6	3.2	32.4	11.6	17.0	3.4	82.4	28.4	470.4	86.9	898.4	84.9	1523.8	88.7
Ft. Sask. L.	46.4	14.0	66.0	24.0	5.4	2.3	115.0	36.5	82.8	20.3	212.6	40.0	546.4	42.6
Sturgeon R	1.8	0.6	.4	.2	3.0	2.1	35.2	12.9	1956.8	454.2	438.4	118.4	2446.0	510.1
Sturgeon L	13.2	7.4	1.2	.7	1.2	.4	35.2	6.3	851.2	292.4	126.2	43.3	1060.8	261.1
Vinca Bridge R	50.4	5.6	177.2	34.8	12.8	2.3	91.2	29.6	332.8	86.5	606.0	26.6	1278.6	101.5
Vinca Bridge L	56.4	6.1	16.2	4.1	5.8	2.6	215.4	37.7	815.8	167.7	489.6	81.9	1610.6	273.9
Pakan Bridge R	35.2	12.3	54.6	15.2	30.6	17.0	22.0	9.8	356.8	227.1	437.0	145.3	945.2	379.1
Pakan Bridge L	59.0	9.4	33.2	13.9	16.4	9.5	22.8	2.5	55.6	14.7	187.4	47.5	381.2	91.9

*R: right bank
**L: left bank

Table 4. Summer 1982, mean and standard error of major zoobenthic parameters

	Ephemeroptera		Trichoptera		Plecoptera		Nematoda		Oligochaeta		Chironomidae		Total Numbers		Total No Taxa		H	
	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE	$\bar{x}$	± SE
Devon R*	1.5	1.1	39.0	5.8	14.4	2.2	12.0	3.0	56.0	8.6	19.8	4.9	161.8	18.9	21.6	0.7	3.656	0.057
Devon L**	6.6	1.3	5.0	1.8	5.0	0.7	2.8	1.3	27.8	6.7	13.2	2.0	79.4	5.9	16.0	.5	3.269	0.094
E.L. Smith R	20.0	4.7	41.2	4.8	13.4	2.8	3.6	3.1	30.0	6.0	59.4	6.1	195.0	25.2	25.2	1.5	4.100	0.083
E.L. Smith L	2.6	4.	8.8	6.6	1.6	0.5	8.4	2.0	28.6	10.2	24.4	3.7	77.4	18.6	13.8	1.2	3.091	0.139
Rossdale R	3.0	1.4	8.4	5.2	1.2	0.6	25.2	5.3	31.8	17.6	48.2	29.6	121.0	59.2	14.4	1.9	3.066	0.121
Rossdale L	46.0	8.7	30.2	4.3	25.8	4.6	21.8	3.4	31.6	7.8	159.0	12.3	327.2	33.0	26.8	.7	3.284	0.065
50th Street R	23.6	4.8	21.6	2.5	.8	0.6	65.8	5.0	61.2	11.27	150.0	16.9	332.8	30.8	23.8	.9	3.304	0.050
50th Street L	47.0	14.0	33.2	9.3	14.2	2.6	36.0	10.0	71.6	16.6	137.2	11.7	367.6	29.3	26.6	1.5	3.659	0.069
Rundle R	35.4	3.0	47.8	19.4	20.0	4.6	5.2	2.1	911.6	229.0	240.6	33.2	1262.8	286.1	18.2	1.4	1.900	0.031
Rundle L	276.2	218.4	223.2	180.3	15.6	4.9	42.4	7.2	94.6	20.2	114.2	14.5	783.2	403.3	28.0	1.2	3.400	0.321
Beverly Bridge R	0.6	.4	1.4	1.0	.0	0.0	20.8	5.3	71.0	13.5	161.6	33.6	257.2	48.6	11.2	1.0	2.440	0.100
Beverly Bridge L	11.4	3.0	4.6	1.8	1.6	0.9	417.6	86.4	164.8	24.5	236.0	26.8	841.6	107.5	16.4	1.3	2.278	0.169
Cloverdale R	114.4	21.6	30.6	2.3	3.4	1.5	98.2	11.7	725.0	135.6	463.2	66.0	1440.4	185.4	21.0	1.6	2.527	0.107
Cloverdale L	110.6	17.3	96.6	31.0	19.2	5.0	21.6	9.3	79.2	14.3	420.4	53.5	767.4	65.1	24.8	1.1	2.872	0.103
Ft. Sask. R	186.6	122.4	64.8	31.7	2.8	1.4	44.8	11.1	588.2	185.8	247.6	25.6	1150.6	131.8	24.0	1.8	2.631	0.246
Ft. Sask. L	10.4	1.6	3.6	1.2	0.2	0.2	28.2	9.7	271.0	50.4	104.2	10.5	425.0	6.10	17.2	1.3	2.484	0.138
Sturgeon R	167.8	47.6	36.8	7.6	3.0	1.8	10.2	1.2	325.4	10.8	163.21	16.6	721.8	59.8	24.2	1.3	2.911	0.094
Sturgeon L	43.8	12.8	17.6	4.2	.2	0.2	11.2	4.6	251.6	17.5	98.0	6.1	458.4	27.8	25.0	1.9	3.127	0.228
Vinca Bridge R	361.0	41.5	56.8	17.9	4.6	2.1	29.0	5.4	464.6	47.5	459.2	44.3	1384.2	92.7	24.0	.5	2.835	0.065
Vinca Bridge L	38.4	2.2	24.8	5.1	2.4	0.7	23.4	32.8	185.0	34.1	556.2	51.3	853.2	73.9	22.8	.9	2.702	0.073
Pakan Bridge R	371.8	41.4	35.4	6.1	9.8	2.4	38.2	12.2	186.4	27.5	155.8	13.7	1012.8	48.9	25.4	.2	3.373	0.110
Pakan Bridge L	426.0	79.6	63.6	22.0	43.0	18.4	22.4	5.5	85.8	4.3	261.8	34.5	944.8	126.7	27.0	2.0	3.532	0.117

*R: right bank
**L: left bank

Table 5. Fall 1982, mean and standard error of major zoobenthic parameters

	Ephemeroptera		Trichoptera		Plecoptera		Nematoda		Oligochaeta		Chironomidae		Total Numbers	
	$\overline{x}$ ±	SE	$\overline{x}$ ±	SE	$\overline{x}$ ±	SE	$\overline{x}$ ±	SE	$\overline{x}$ ±	SE	$\overline{x}$ ±	SE	$\overline{x}$ ±	SE
Devon R*	28.8	14.4	6.0	0.9	112.4	22.1	3.2	1.0	11.8	3.2	12.8	3.7	218.2	45.7
Devon L**	16.6	2.1	2.4	0.9	27.0	3.2	.8	0.2	10.2	3.3	8.4	1.9	90.4	4.0
E.L. Smith R.	.8	0.2	0.2	0.2	3.6	2.0	21.6	5.3	30.8	4.7	113.6	25.5	184.2	4.3
E.L. Smith L.	.0	0.0	0.2	0.2	0.8	0.5	14.2	3.0	144.4	29.4	7.8	2.0	179.8	33.7
Rossdale R	1.4	0.5	0.0	0.0	1.6	0.4	64.4	12.6	205.4	37.9	66.4	7.5	349.2	56.5
Rossdale L	.2	0.2	0.4	0.2	0.2	0.2	68.8	20.5	1589.0	262.4	19.2	7.6	1724.2	266.3
50th Street R	16.0	7.8	0.4	0.2	1.0	0.3	136.8	9.1	3851.6	492.3	328.2	65.4	4349.6	485.9
50th Street L	3.4	1.0	0.4	0.2	1.2	0.2	36.8	6.6	4304.8	749.2	312.0	81.6	4694.4	817.9
Rundle R	.8	0.6	0.2	0.2	0.6	0.4	18.8	4.4	26470.4	4000.8	364.2	128.3	26861.0	3984.3
Rundle L	104.6	11.3	2.2	1.0	72.4	5.0	87,.2	7.9	2832.8	204.8	824.4	75.2	4036.8	265.9
Beverly Bridge R	5.0	1.0	.2	0.2	0.4	0.2	30.4	4.7	7876.8	558.8	375.8	40.6	8308.2	576.4
Beverly Bridge L	27.2	13.5	1.6	1.4	11.2	3.4	44.8	6.5	1418.4	247.1	332.0	54.4	1871.0	268.6
Cloverdale R	75.2	26.4	66.8	21.5	6.6	2.1	102.4	24.0	2202.8	411.5	1260.6	192.7	3876.6	424.1
Cloverdale L	.8	0.6	.4	0.4	0.2	0.2	23.2	4.6	3999.2	680.1	19.2	5.0	4074.4	690.5
Ft. Sask. R	72.6	28.1	51.4	20.0	15.2	4.8	181.6	36.5	7040.0	2154.4	760.0	162.4	8379.2	1947.7
Ft. Sask. L	106.2	37.2	4.6	1.2	9.8	3.7	72.3	72.3	558.4	181.1	1577.0	223.2	2800.2	435.8
Sturgeon R	88.4	21.4	131.6	33.2	8.8	2.2	77.6	17.0	2864.0	1246.0	806.4	96.4	4143.2	1146.5
Sturgeon L	42.2	24.9	8.4	3.7	4.8	2.1	79.2	10.2	719.2	140.1	312.4	54.8	1369.8	211.1
Vinca Bridge R	73.8	6.7	35.8	7.0	0.8	0.2	51.6	11.2	836.8	48.0	977.4	55.6	2005.0	70.3
Vinca Bridge L	434.8	57.3	286.2	69.4	2.0	44.0	2.7	2.7	406.4	111.9	993.2	118.9	2517.4	71.0
Pakan Bridge R	568.8	156.7	31.2	11.2	27.2	8.2	40.8	16.1	361.6	75.5	622.4	99.2	1679.0	263.9
Pakan Bridge L	646.4	149.2	64.8	30.8	58.4	17.3	31.2	9.1	251.2	33.5	1096.8	92.9	2288.4	190.0

*R: right bank
**L: left bank

specimens per sample in the fall. Densities remained high for all right-bank sites downstream of Rundle Footbridge except Beverly Bridge, where lower numbers occurred in spring and summer. There was a slight decline in average densities per site at Pakan Bridge.

The trend for left-bank sites was similar to that observed for the right-bank sites. Although increases in numbers per sample were less pronounced for left-bank sites, the changes were evident somewhat further upstream (i.e., at Rossdale). The highest total numbers for left-bank sites (4,800 specimens per sample at 50th Street) were also encountered in the fall.

3.2.2 Number of Individuals Per Major Taxon

The distribution of numbers among taxa is presented in Figures 2 to 7; basic statistics for individual parameters are given in Tables 3 to 5.

A progressive change was evident in the community composition from upstream sites to downstream sites. Chironomidae, Oligochaeta and Nematoda commonly represented about half of total numbers at Devon; the other half was composed mainly of Plecoptera, Ephemeroptera, Trichoptera, and a variety of taxa included as "remaining groups". In downstream direction and within the city limits, the number of chironomids, nematodes and especially oligochaetes often increased dramatically. These three groups represented up to 98% of the total numbers. Consequently, the percentage of mayflies, stoneflies and caddisflies was less than 5%, particularly at right-bank sites, even though the actual numbers for these three groups were usually slightly higher than at Devon. Further downstream, a second major change occurred when numbers of stoneflies, mayflies, caddisflies, and "remaining groups" showed much larger increases. However, numbers of chironomids, oligochaetes and nematodes also remained high. The ratios of numbers for major taxa to total numbers were comparable for Devon and Pakan Bridge, even though actual numbers were more than an order of magnitude greater at Pakan Bridge.

The locations at which these shifts in community composition occurred varied from left bank to right bank, and from one sampling period to another. In general the number of Chironomidae, Oligochaeta, and Nematoda increased downstream from Rossdale at left-bank sites, and increased downstream from 50th Street Footbridge at right-bank sites. The increase in Ephemeroptera, Plecoptera, and Trichoptera numbers was evident as far upstream as Clover Bar for left-bank sites; at right-bank sites, these numbers did not increase appreciably before Vinca Bridge.

3.2.3 Shannon-Wiener Diversity

Figure 8 summarizes average values for the Shannon-Wiener diversity index for left-bank and right-bank sites for the three sampling periods. Basic statistics for this parameter are given in Tables 3 to 5.

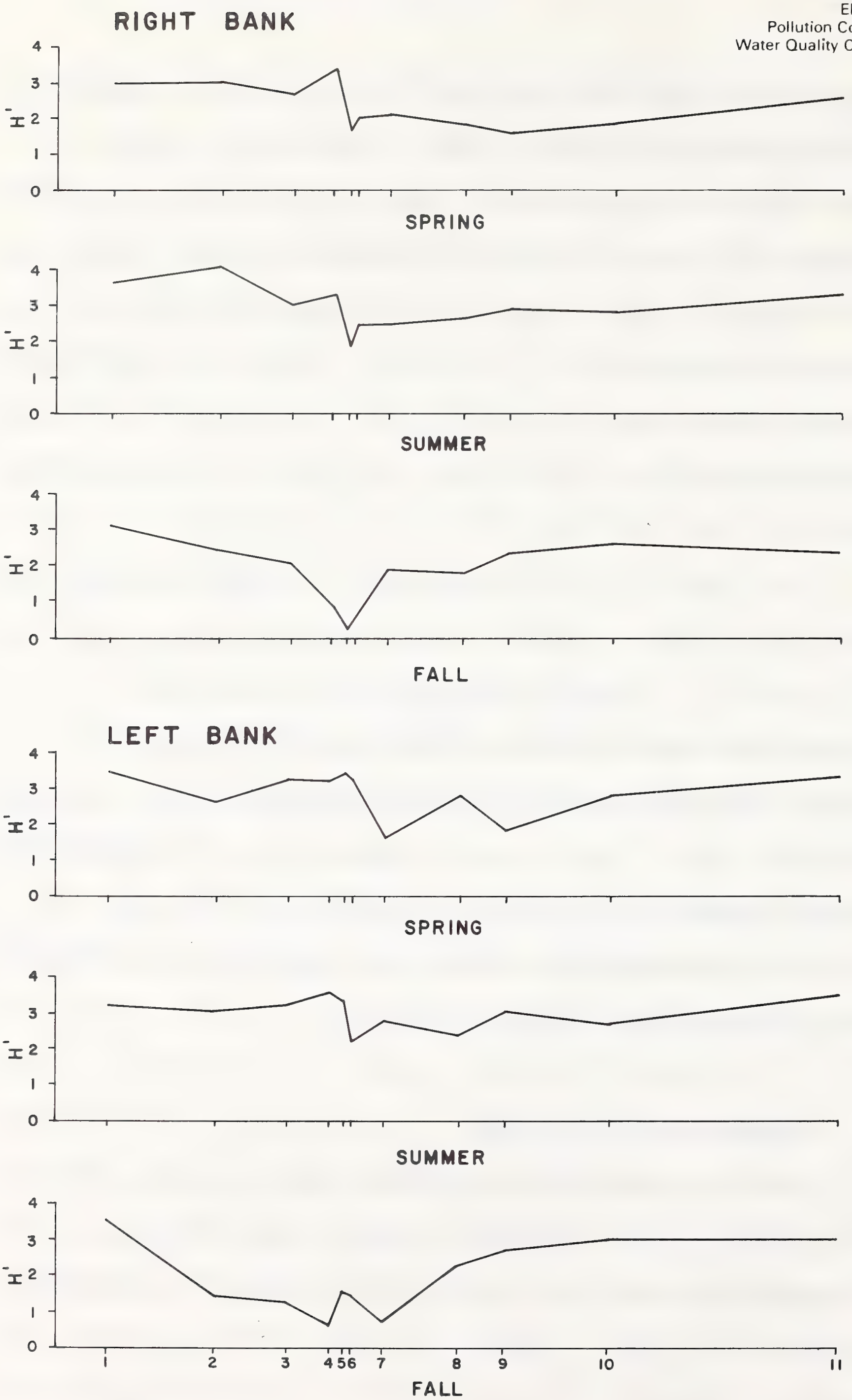


FIGURE 8 . SHANNON-WIENER DIVERSITY (H') .
Refer to Table 1c for site labels.

Diversity values calculated for the benthic invertebrate community of the North Saskatchewan River between Devon and Pakan Bridge ranged from a maximum of 4.100 at E.L. Smith (summer, right-bank site) to a minimum of 0.234 at Rundle Footbridge (fall, right-bank site). The patterns exhibited by the Shannon-Wiener diversity index in downstream direction were similar for all three data sets, although variations were more pronounced in the fall.

Right-bank sites upstream of Edmonton had the highest diversity values. H' declined gradually in downstream direction, and lowest values occurred at Rundle Footbridge. Values for H' remained low between Rundle Footbridge and Sturgeon in the spring, whereas a gradual increase in H' occurred from Rundle Footbridge downstream in summer and fall. Diversity values for the most downstream right-bank sites (Vinca Bridge and Pakan Bridge) were comparable to the values for Devon or E.L. Smith in the corresponding seasons.

For left-bank sites, diversity remained fairly stable in downstream direction until Beverly Bridge in spring or Rundle Footbridge in summer. Lowest H' values for these seasons occurred at the next downstream site in each case (i.e., Clover Bar and Beverly Bridge, respectively). Downstream of the latter two sites, diversity values increased irregularly. The pattern for the fall differed from those for spring and summer by the sudden drop in diversity at E.L. Smith and the persistence of low values until Clover Bar. Similar to right-bank sites, the diversity values for the most downstream left-bank sites were comparable to the values for Devon.

3.3 Multivariate Analyses

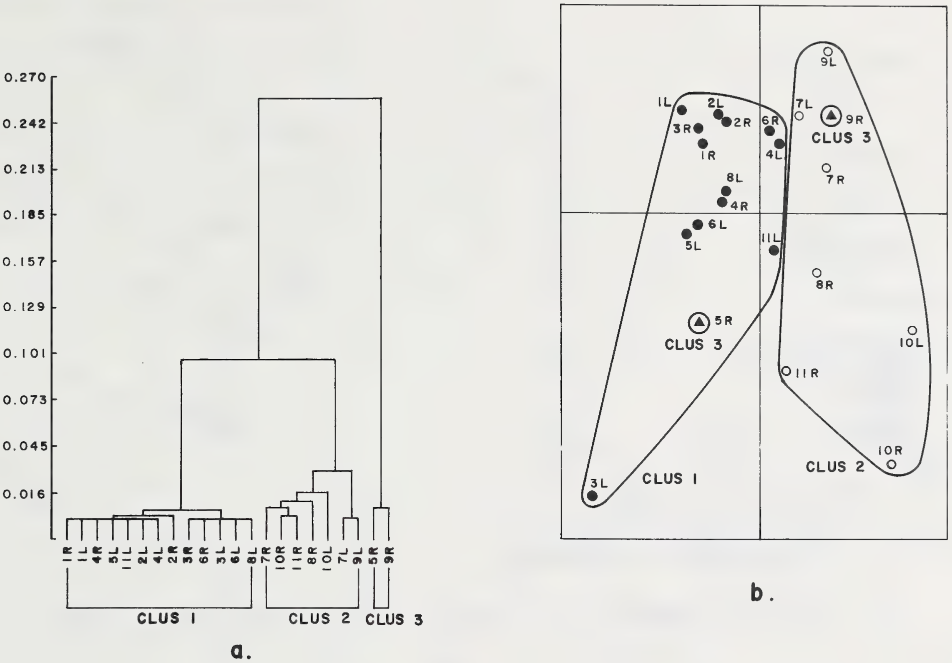
3.3.1 Cluster Analysis

The results of cluster analyses are presented as dendrograms in Figures 9, 10, and 11 for spring, summer, and fall, respectively.

The cluster analysis of spring data identified 3 major clusters. The first cluster (clus-1) grouped all sites from Devon to 50th Street Footbridge, the left-bank site at Rundle Footbridge, all sites at Fort Saskatchewan and Pakan Bridge, and both sites at Beverly Bridge. Clus-2 grouped both sites at Clover Bar, both sites at Vinca Bridge, the right-bank site at Fort Saskatchewan, and the left-bank site at Sturgeon. Clus-3 grouped the right-bank sites at Rundle and Sturgeon.

The cluster analysis of the summer data identified only two clusters. Clus-1 grouped all sites except the Sturgeon left-bank site, which constituted clus-2.

Three major clusters were identified by the analysis of the fall data set. Clus-1 and clus-2 resulted from the fusion of several sub-clusters. The differences in similarity coefficients at the fusion points of these sub-clusters were too small to be significant. However, for reasons which will become apparent later (results of principal component analysis), clus-1 was divided into clus-1a, comprised of sites upstream of Edmonton, and clus-1b, comprised of all sites downstream of Edmonton (i.e., downstream of sites in clus-2 and clus-3). Specifically, clus-1a grouped both sites at Devon, both



a.

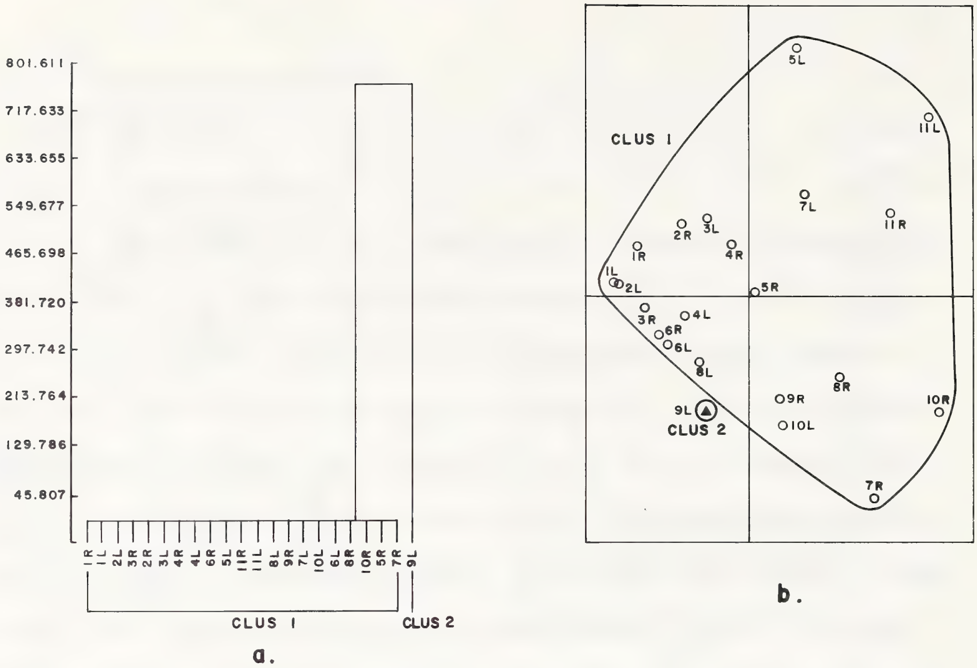
b.

a. Cluster analysis.

b. Principal component analysis:
site groups are those identified in spring cluster analysis.

Refer to Table 1c for site labels.

FIGURE 9. MULTIVARIATE ANALYSIS OF ZOOBENTHIC DATA FROM SPRING 1982



a.

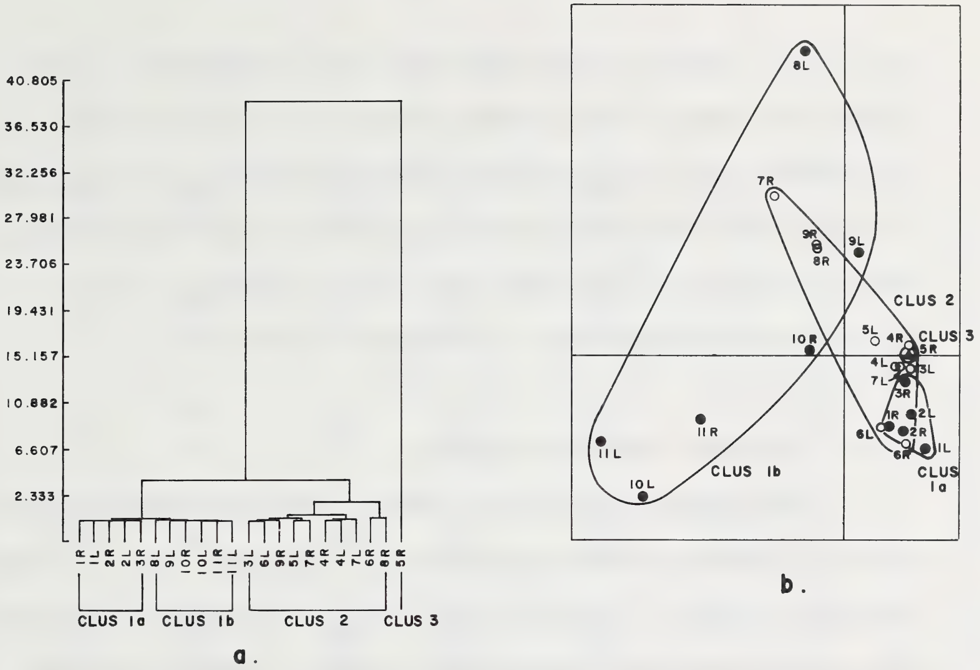
b.

a. Cluster analysis.

b. Principal component analysis :
site groups are those identified in summer cluster analysis .

Refer to Table 1c for site labels.

FIGURE 10. MULTIVARIATE ANALYSIS OF ZOOBENTHIC DATA FROM SUMMER 1982



a. Cluster analysis.

b. Principal component analysis:
site groups are those identified in fall cluster analysis.

Refer to Table 1c for site labels.

FIGURE 11. MULTIVARIATE ANALYSIS OF ZOOBENTHIC DATA FROM FALL 1982

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sites at E.L. Smith, and the right-bank site at Rossdale; clus-1b grouped both sites at Vinca Bridge, both sites at Pakan Bridge, and the left-bank sites at Fort Saskatchewan and Sturgeon; clus-2 grouped all sites from 50th Street Footbridge to Clover Bar, the left-bank site at Rossdale, and the right-bank site at Sturgeon; clus-3 consisted of the right-bank site at Rundle Footbridge.

3.3.2 Principal Component Analysis

The eigenvalues[1] and percentage variance explained by each principal component in the analysis of spring, summer, and fall data are given in Table 6. The first two principal components explained the largest proportion of the sample variance. Because the third principal component also explained a considerable fraction of the variance, it was included in the analysis.

Taxa which accounted for most of the variance in each principal component are listed in Table 7; the eigenvector values are also given.

3.3.3 Major Characteristics of the Taxa identified by Principal Component Analysis

An appraisal of the list of taxa identified by PCA as being the most critical in the data set (Table 7) showed that a total of 31 different taxa had high eigenvector[1] values in the data sets for the three sampling seasons. Some of these taxa (i.e., Tricorythodes,

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[1] See Section 2.4.1 of Methods for Definitions

TABLE 6 Eigen values and percentage variance explained by each eigenvector for Spring, Summer, and Fall data.

SPRING Eigen Values											
5.96	4.16	3.11	2.36	1.99	1.74	1.48	1.29	1.13	0.87	0.85	0.64
0.37	0.35	0.24	0.14	0.12	0.10	0.06	0.04	0.01	0.00	0.00	0.00
0.00	-0.00	-0.00	-0.00								
Percentage Variance											
21.27	14.87	11.10	8.41	7.11	6.22	5.27	4.53	4.04	3.10	3.05	2.29
1.34	1.24	0.86	0.50	0.43	0.34	0.22	0.13	0.03	0.00	0.00	0.00
0.00	-0.00	-0.00	-0.00								
SUMMER Eigen Values											
6.11	4.62	2.99	2.02	1.68	1.53	1.33	1.08	0.87	0.84	0.57	0.38
0.28	0.26	0.20	0.14	0.07	0.02	0.01	0.00	0.00	0.00	0.00	0.00
0.00											
Percentage Variance											
24.43	18.50	11.97	8.07	6.71	6.10	5.34	4.33	3.47	3.37	2.30	1.51
1.11	1.05	0.78	0.57	0.26	0.07	0.03	0.02	0.01	0.00	0.00	0.00
0.00											
FALL Eigen Values											
8.01	4.28	3.08	2.51	1.99	1.53	1.44	1.19	0.96	0.87	0.61	0.45
0.36	0.28	0.25	0.11	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00							
Percentage Variance											
27.62	14.75	10.63	3.66	6.88	5.29	4.38	4.09	3.31	3.01	2.10	1.54
1.26	0.96	0.86	0.39	0.12	0.05	0.03	0.01	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00							

TABLE 7. List of taxa which have high positive or negative scores for first three vectors

VECTOR 1	VECTOR 2	VECTOR 3
Spring 21% (*)	Spring 15% (*)	Spring 11% (*)
Chironomini 0.328	Tanytarsini 0.194	Naididae 0.337
Tubificidae 0.272	Ceratopogonidae 0.111	Turbellaria 0.311
Mermithoidea 0.241	Isoperla -0.392	Chironomid pupae 0.298
Tanypodinae 0.238	Chironomid pupae -0.347	Tubificidae 0.218
Tricorythodes 0.238	Tanypodinae -0.299	Acari -0.365
Psychomyia 0.222	Hydropsychidae -0.273	Enchytraeidae -0.318
Ferrissia 0.217	Psychomyia -0.265	Glossosoma -0.302
Baetis -0.300		Nematoda -0.278
Alloperla -0.296	Summer 19% (*)	
Rhithrogena -0.287		Summer 12% (*)
Heptageniidae -0.242	Unid. Plecoptera 0.329	
	Ephemeroptera Nymphules 0.304	Hycropsychidae 0.462
Summer 21% (*)	Centroptilum 0.296	Orthocladiinae 0.318
	Acari 0.248	Chironomid pupae 0.321
Tricorythodes 0.339	Ferrissia -0.269	Naididae 0.310
Tanpodinae 0.297	Chironomid pupae -0.250	Tubificidae -0.292
Heptageniidae 0.296	Tubificidae -0.226	Psychomyia -0.257
Pseudocleon 0.280	Tanypodinae -0.224	Tricorythodes -0.217
Orthocladiinae 0.280		
Enchytraeidae -0.247	Fall 15% (*)	Fall 11% (*)
Fall 28% (*)	Enchytraeidae 0.194	Elmidae 0.445
	Psychomyia 0.279	Caenis 0.444
Enchytraeidae 0.200	Mermithoidea -0.397	Tanytarsini 0.292
Tricorythodes -0.310	Capniidae -0.384	Tubificidae 0.187
Heptagenia -0.310	Ferrissia -0.380	Enchytraeidae -0.231
Isoperla -0.303	Orthocladiinae -0.331	Chloroperlidae -0.293
		Rhithrogena -0.322

(*) indicates the variance explained by each individual vector.

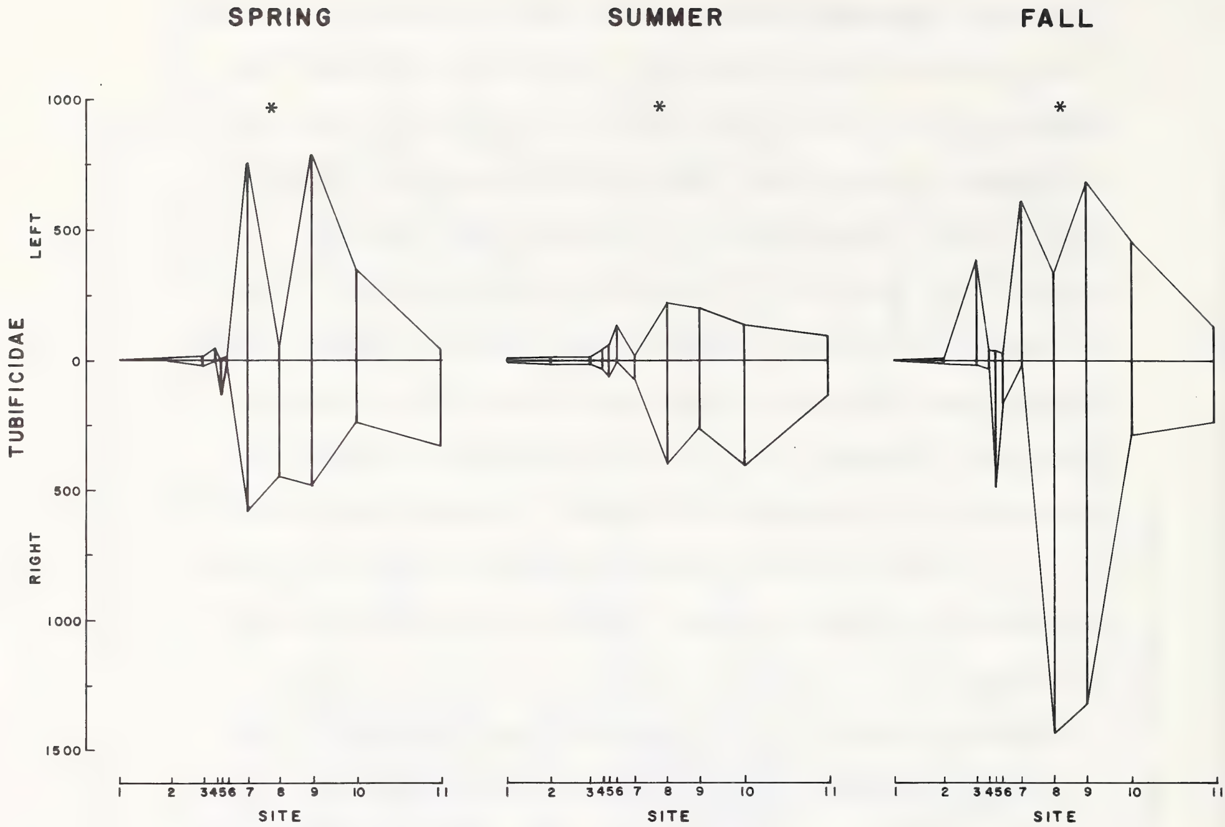
Ferrissia, *Psychomyia*, Enchytraeidae, and Tubificidae) explained a large portion of the variance in all three data sets; some taxa accounted for a large fraction of the variance in two data sets (i.e., *Rhithrogena*, Heptageniidae, Hydropsychidae, *Isoperla*, Tanytarsini, Tanypodinae, Orthocladiinae, Chironomidae pupae, Naididae, Mermithoidea, and Acari). The remaining taxa explained a large portion of the variance in only one data set (i.e., *Baetis*, *Caenis*, *Centroptilum*, *Heptagenia*, *Pseudocleon*, Ephemeroptera nymphules, *Glossosoma*, *Alloperla*, Capniidae, Chloroperlidae, undetermined Plecoptera, Ceratopogonidae, Chironomini, Nematoda, and Elmidae).

In general, benthic invertebrates will show one of three responses to effluent discharge, depending on the nature of the discharge:

- a positive response (i.e., numbers increase downstream of the discharge)
- a negative response (i.e., numbers decrease downstream of the discharge)
- no change (i.e., no change in numbers downstream of the discharge)

A further distinction can be made in the first 2 types of response between taxa which show a gradual response and those which show a sudden, though possibly short-lived, response. The densities of taxa illustrating each type of response in the North Saskatchewan River are shown in Fig. 12.

Most taxa showed a gradual, positive response. Three of the five taxa identified in spring, summer, and fall by principal component analysis were the most typical examples of this type of response. *Tricorythodes*, *Ferrissia*, and *Psychomyia* were present at



* Indicates the season in which a taxon explains a large fraction of the sample variance .

FIGURE 12 . TAXA SHOWING CHARACTERISTIC DENSITY CHANGES IN THE NORTH SASKATCHEWAN RIVER IN THE VICINITY OF EDMONTON .

Refer to Table 1c for site labels.

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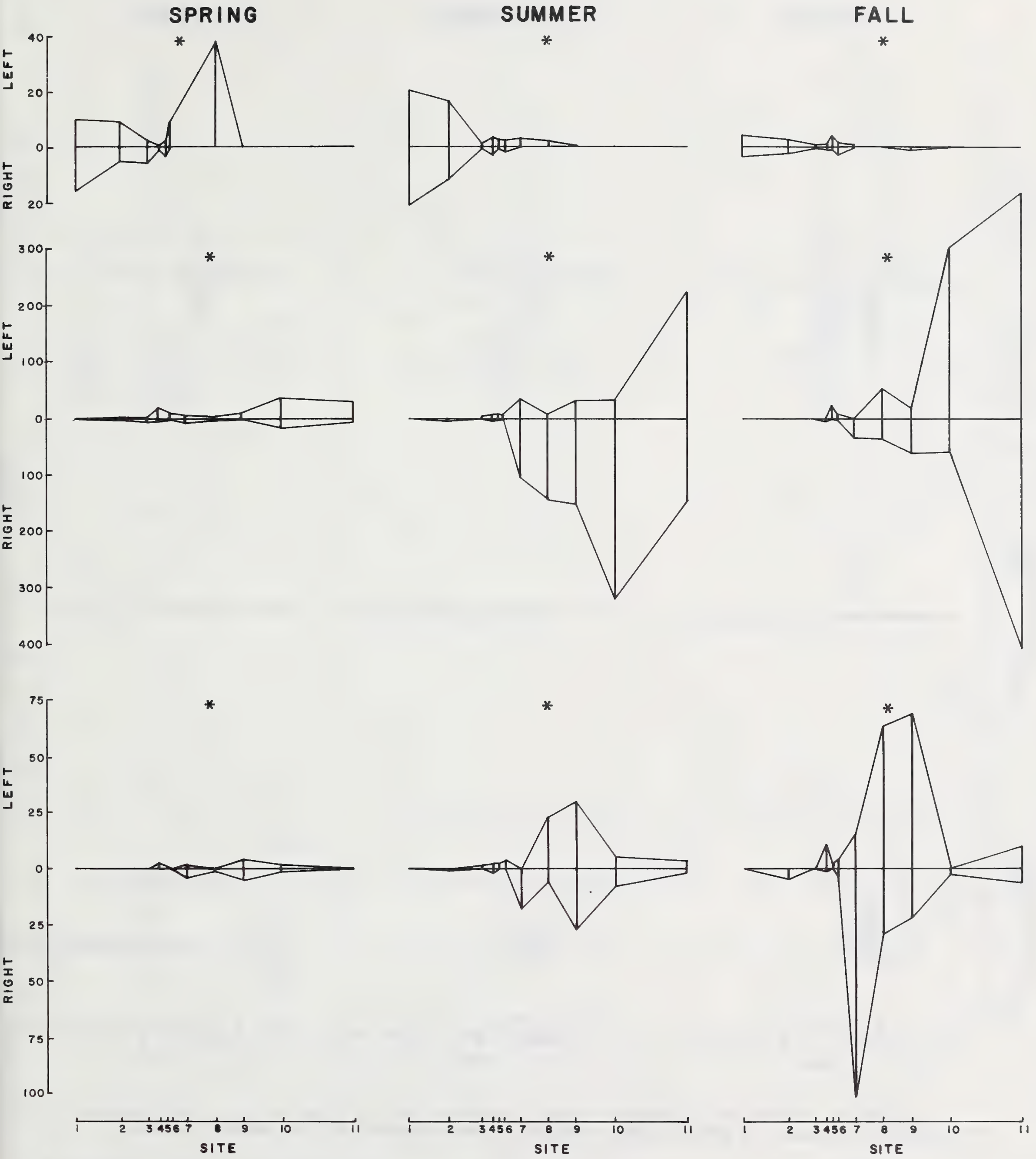

* Indicates the season in which a taxon explains a large fraction of the sample variance .

FIGURE 12 Continued .

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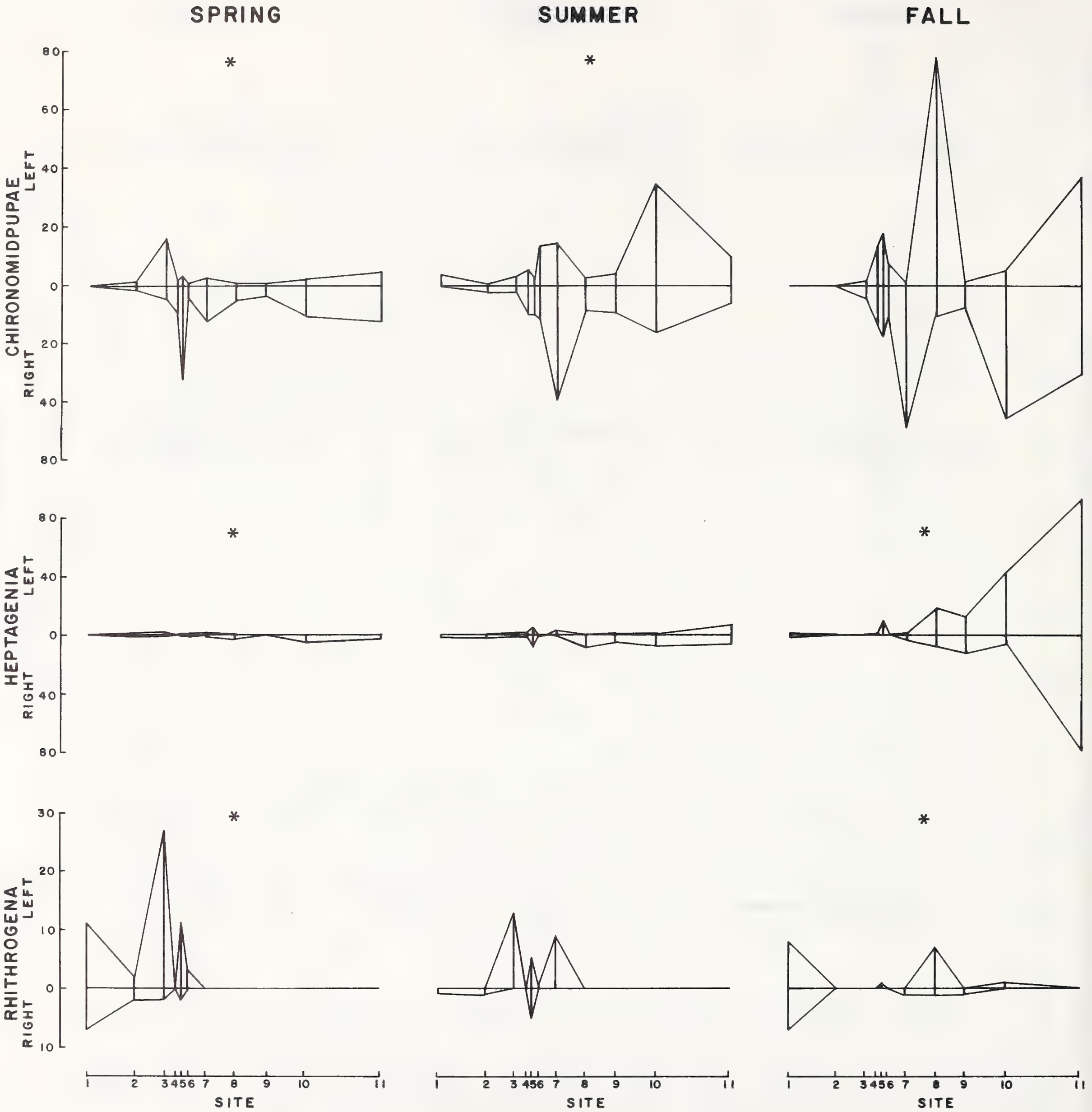

* Indicates the season in which a taxon explains a large fraction of the sample variance .

FIGURE 12 Continued .

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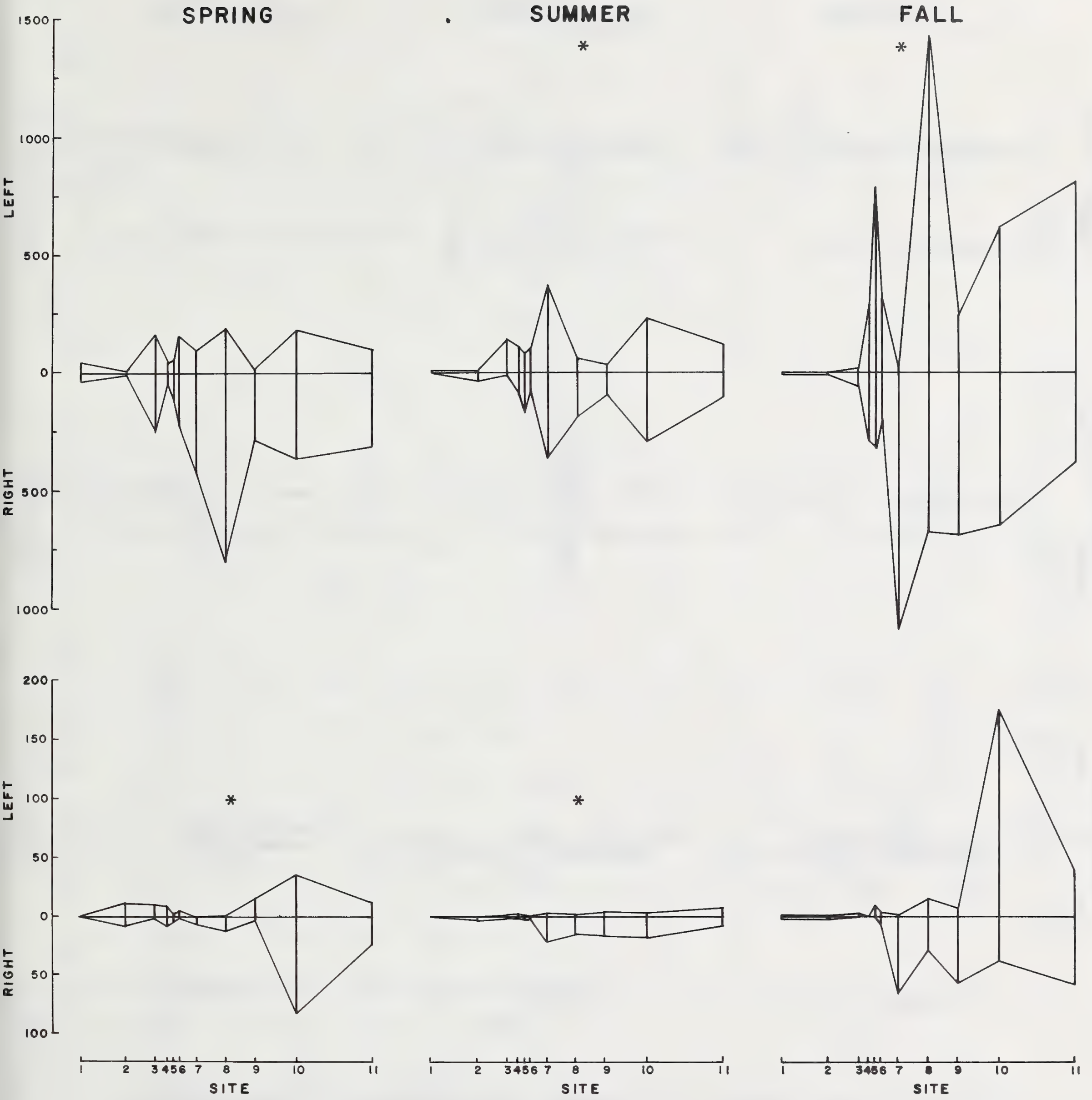

* Indicates the season in which a taxon explains a large fraction of the sample variance .

FIGURE 12 Continued .

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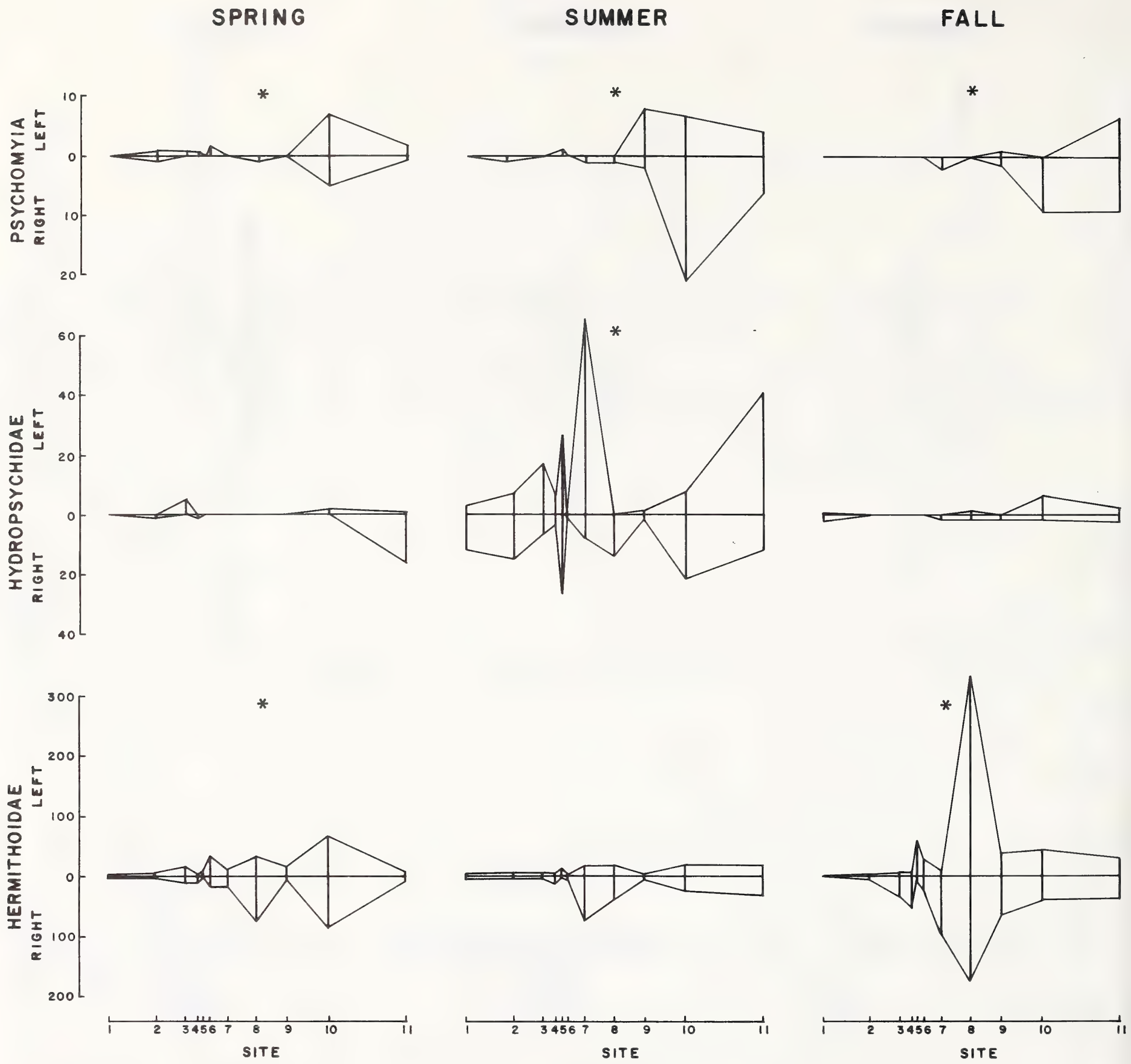

* Indicates the season in which a taxon explains a large fraction of the sample variance .

FIGURE 12 Continued .

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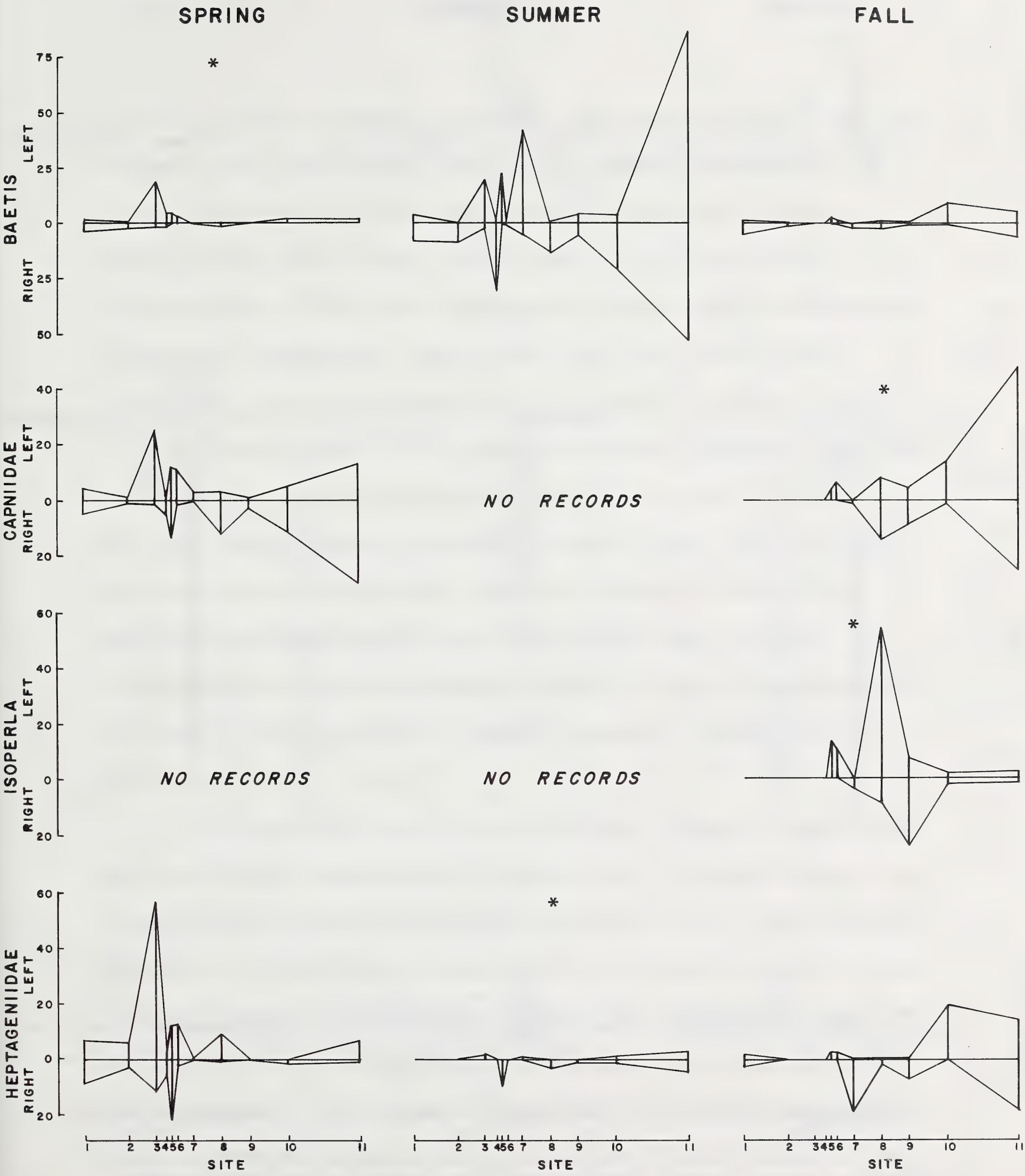

* Indicates the season in which a taxon explains a large fraction of the sample variance.

FIGURE 12 Continued

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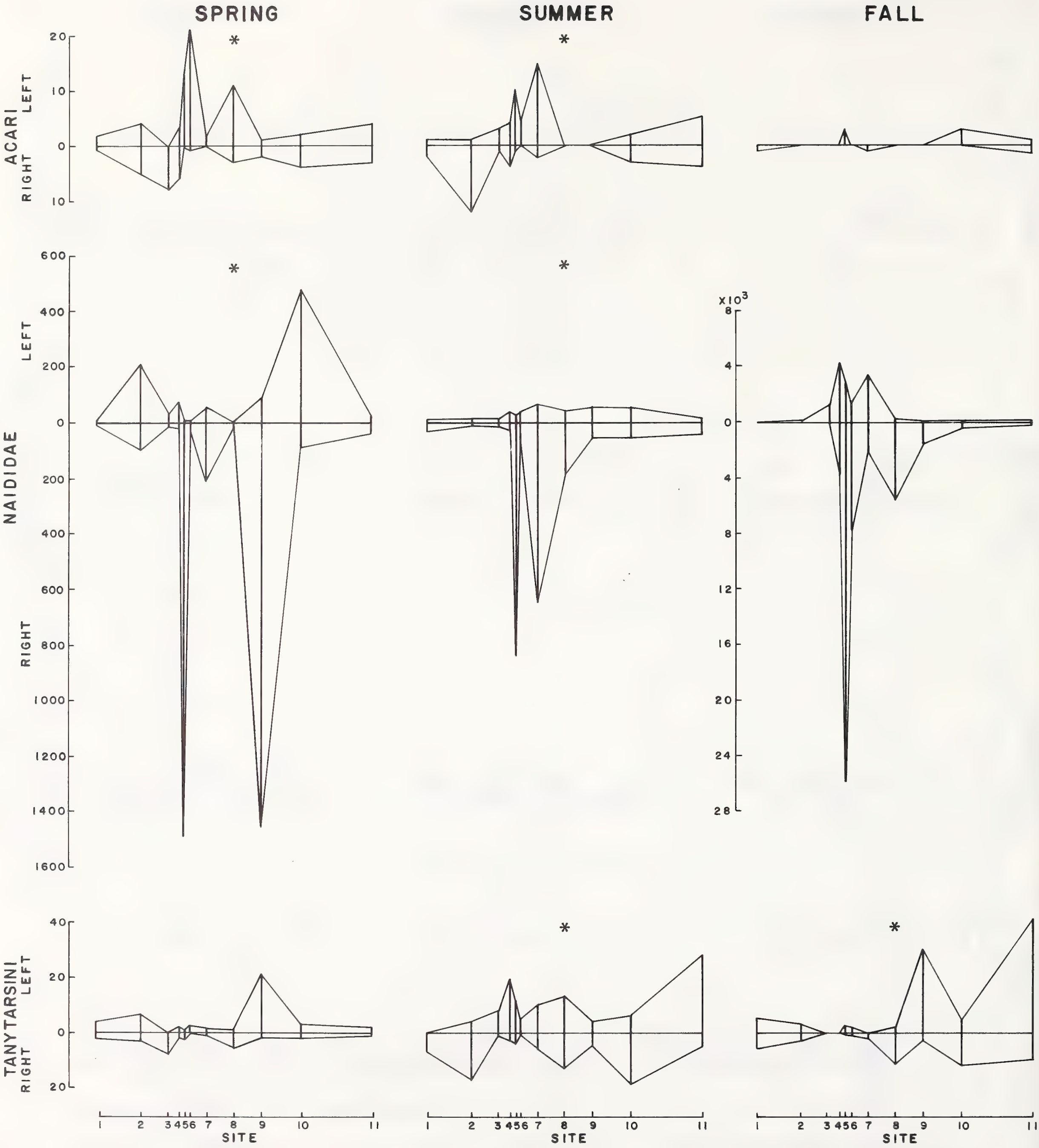

* Indicates the season in which a taxon explains a large fraction of the sample variance.

FIGURE 12 Continued.

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very low numbers in samples from sites upstream of Edmonton, but they showed gradual and definite increases in numbers downstream of the city. The response of these three genera at the sites farthest downstream was inconsistent. Other taxa such as Tanypodinae, Orthocladiinae, Tubificidae, *Heptagenia*, Heptageniidae, Mermithoidea, *Psychomyia*, *Pseudocleon*, *Isoperla*, and Capniidae showed similar trends, but were often rather well represented at upstream sites.

Only two taxa showed a gradual negative response. These were Enchytraeidae, which was selected 3 times by principal component analysis, and *Rhithrogena*, which was selected twice, once in spring and once in fall, by principal component analysis. The upstream densities for these two taxa were low and both taxa occurred occasionally at sites downstream of Edmonton. *Baetis* showed opposite responses in spring and fall: numbers decreased in spring and increased in fall.

Naididae was the only taxon to show a dramatic, short-lived positive response downstream of certain sites. Although naidids were one of the most typical components at certain sites in the fall, they accounted for only a small fraction of the variance in the first three principal components (eigenvector values 0.089, 0.046, and 0.039 in vector 1, 2, and 3, respectively), even though they accounted for a large fraction of the variance in the remaining principal components (e.g., eigenvector values 0.255, 0.117, 0.225, -0.310, 0.363, -0.528, -0.418 in vectors 4 to 10, respectively).

Only unidentified, small Hydropsychidae larvae did not show notable or consistent trends in the river section under study.

3.3.4 Relationships between Results from Cluster Analysis and Principal Component Analysis

Scattergrams obtained by principal component analysis are represented in Figures 9, 10, and 11 for spring, summer, and fall data, respectively.

Hypotheses formulated from the results of one analysis technique gain strength when these results are concordant with the results of another technique. Ideally, site clusters identified by cluster analysis should correspond to sites grouped by principal component analysis projections, and these site groups would have interpretable meanings in the context of the study.

The boundaries of site groups which were identified by cluster analysis in the 3 seasons are indicated on the corresponding principal component analysis projections (Figs. 9b to 11b).

3.3.4.1 Spring

Cluster analysis showed that in spring, sites fell into 3 major groups: clus-1, clus-2, clus-3 (Fig. 9a). Principal component analysis (Fig. 10b) indicated that the separation between clus1 and clus-2 was due mainly to density differences for taxa which were most characteristic for the first vector (Table 7). Sites from clus-2 were characterized by higher numbers of Chironomini, Tubificidae, Mermithoidea, Tanypodinae, Tricorythodes, Psychomyia and Ferrissia, whereas sites from clus-1 were characterized by Baetis, Alloperla, Rhithrogena, and Heptageniidae. The second vector (Table 7) explained differences within each of clus-1 and clus-2, which were due mainly to variations in abundance of Tanytarsini and Ceratopogonidae in one direction, and of Isoperla, Chironomid pupae, Tanypodinae, Hydropsychidae, and Psychomyia in the other. The third vector (Table 7) explained why the clus-3 right-bank sites at Rundle Footbridge and Sturgeon (typified by a predominance of Naididae, Turbellaria, Chironomidae pupae, and Tubificidae) were different from other sites (typified by Acari, Enchytraeidae, Glossosoma, and Nematoda).

3.3.4.2 Summer

Two site groups were differentiated by cluster analysis for the summer data (Fig. 10a). A comparison of cluster analysis and principal component analysis (Fig. 10) did little to clarify relationships among summer data. The separation of sites into only two clusters and the absence of any sub-clustering among sites was unexpected. However, an inspection of the relative locations of sites in the principal component analysis projections revealed that sites were projected in an orderly fashion: sites from the upstream locations were furthest from sites from downstream locations, whereas sites in the centre of the study section had an intermediate position on the principal component analysis projection.

3.3.4.3 Fall

Three major clusters (clus-1, clus-2, and clus-3) were identified in the fall data (Fig. 11a). Principal component analysis showed that the distinction between clus-1a and clus-1b was more important than suggested by cluster analysis alone, because both groups were physically separated by clus-2 on the principal component projections. The first vector separated the three site groups on the basis of density differences for Enchytraeidae on the positive side of the axis (+) and for Tricorythodes, Heptagenia, and Isoperla on the negative side (-). The first taxon was more typical of upstream sites, whereas the latter three were more characteristic of downstream sites. Enchytraeidae, Psychomyia (+), and Mermithoidea, Capniidae, Ferrissia Orthocladiinae (-), explain most of the variation in the second vector.

It is difficult to visualize the relative position of site groups when a two-dimensional projection is used to represent three-dimensional space, as is the case in Figure 11b. For example, principal component projections in two dimensions showed quite a bit of overlap between clus-1a and clus-2. However, analysis of the third vector indicated that these two clusters were quite different: Enchytraeidae, Chloroperlidae, and Rhithrogena were more typical of clus-1a, and Elmidae, Caenis, Tanytarsini, and Tubificidae were more typical of clus-2. The amount of overlap between clus-2 and clus-1b was reduced in a similar way in three-dimensional space. Cluster analysis clearly separated the right-bank site at Rundle Footbridge from all other sites; in two-dimensional space, however, principal component analysis showed little difference between this site and clus-2 sites. Naididae was the most typical faunal element at Rundle

Footbridge in the fall. This taxon had low eigenvector values in the first three vectors, but high eigenvector values in the remaining vectors. Such high values in vectors which explain nearly 50% of sample variance suggested that sites with high naidid numbers (e.g., right-bank site at Rundle Footbridge) are significantly different from sites with low naidids numbers.

3.3.5 One-Way Analysis of Variance (ANOVA)

Principal component analysis showed that there were differences in the taxonomic composition of the invertebrate assemblies in the site clusters which were identified by cluster analysis. However, the separation of these site clusters was also evident at a lower level of identification (e.g., major taxonomic groups) utilizing parameters which summarize information for the entire invertebrate assembly (i.e., total invertebrate density, Shannon-Wiener diversity, and total number of taxonomic groups). The statistical significance of differences between cluster means for these parameters was tested with a one-way ANOVA.

3.3.5.1 Spring

The one-way ANOVA performed on the data from the three site groups identified by multivariate analysis in spring showed that there were significant differences in all parameters tested, except for numbers of Trichoptera and Plecoptera (Table 8). Ephemeroptera (mayfly) numbers were significantly higher in the upstream part of

Table 8. Comparison of means for selected benthic parameters between sites groups defined by cluster analysis and principal component analysis for spring 1982 (summary of ANOVA results)

	Summary of results from one-way ANOVA F	p	Summary of results from Student-Newman-Keuls Test
Nematoda (1)	7.62	0.0008	clus-3 < clus-1 < clus-2
Oligochaeta (1)	116.49	0.0000	clus-1 < clus-2 < clus-3
Ephemeroptera (1)	8.40	0.0004	clus-3 = clus-2 < clus-1
Trichoptera (1)	1.85	0.1623	no significant difference
Plecoptera (1)	0.57	0.5679	no significant difference
Chironomidae (1)	31.92	0.0000	clus-1 < clus-2 = clus-3
Total Numbers (1)	100.27	0.0000	clus-1 < clus-2 < clus-3
Total Number of Taxa	22.48	0.0000	clus-3 < clus-2 < clus-1
Shannon-Wiener Diversity	46.75	0.0000	clus-3 < clus-2 < clus-1

1. Tests performed on Log(x+1) transformed data.

2. $df_1 = 3$, $df_2 = 106$; tabulated F values for df_1 and $df_2 = 120$: F(0.05) = 2.68
F(0.01) = 3.95
F(0.001) = 5.79

3. "x = y": means for groups x and y are not significantly different at 0.050 level
"x < y": mean for group x is significantly lower than mean for group y at the 0.050 level

the study section (clus-1). Oligochaete, chironomid, and total invertebrate numbers increased significantly between upstream sites (clus-1) and downstream sites (clus-2); they were highest for right-bank sites at Rundle and Sturgeon (clus-3). The number of taxonomic groups and the Shannon-Wiener diversity declined in downstream direction and were lowest for sites in clus-3.

3.3.5.2 Summer

Because cluster analysis did not identify meaningful groups, no tests were done on cluster means for selected parameters.

3.3.5.3 Fall

The means for the four site groups identified by cluster analysis and principal component analysis differed significantly for all parameters tested (Table 9).

Total invertebrate numbers and oligochaete numbers followed the same pattern. Numbers increased significantly between upstream clus-1a sites and clus-2 sites immediately downstream of Edmonton and in the Fort Saskatchewan area. Although the means for the downstream clus-1b sites were lower than those for clus-2, they were significantly higher than those for clus-1a. Chironomid numbers showed a similar pattern, except that the means between clus-1b and clus-2 were not significantly different. Clus-3 (right-bank site at Rundle Footbridge) had the highest mean for each of the three parameters tested.

Table 9. Comparison of means for selected benthic parameters between site groups defined by cluster analysis and principal component analysis for fall 1982 (summary of ANOVA results)

	Summary of results from one-way ANOVA F	 p	Summary of results from the Student-Newman-Keuls Test
Nematoda (1)	21.10	0.0000	clus-1a = clus-3 < clus-1b = clus-2
Oligochaeta (1)	163.71	0.0000	clus-1a = clus-1b < clus-2 < clus-3
Ephemeroptera (1)	33.26	0.0000	clus-3 = clus-1a < clus-2 < clus-1b
Trichoptera (1)	15.42	0.0000	clus-3 = clus-1a = clus-2 < clus-1b
Plecoptera (1)	3.95	0.0103	clus-3 = clus-2; clus-1a = clus-2; clus-3 < clus-1a < clus-1b
Chironomidae (1)	38.64	0.0000	clus-1a < clus-2 < clus-1b = clus-3
Total Numbers (1)	249.15	0.0000	clus-1a < clus-1b < clus-2 clus-3
Total Number of Taxa	18.42	0.0000	clus-3 < clus-1a = clus-2 < clus-1b
Shannon-Wiener Diversity	47.61	0.0000	clus-3 < clus-2 < clus-1a = clus-1b

1. Tests performed on Log(x+1) transformed data.

2. $df_1 = 2$, $df_2 = 107$; tabulated F values for df_1 and $df_2 = 120$: F(0.05) = 3.07
F(0.01) = 4.79
F(0.001) = 7.32

3. "x = y": means for groups x and y are not significantly different at 0.050 level
"x < y": mean for group x is significantly lower than mean for group y at the 0.050 level

The parameter means for Plecoptera, Ephemeroptera, and Trichoptera were lowest for clus-3 and highest for clus-1b. However, the differences between means for clus-3 and the remaining site groups were not as great as might have been expected. Ephemeroptera (mayfly) numbers were not significantly different between clus-3 and clus-1a. Caddisfly numbers were not significantly different among clus-1a, clus-2, and clus-3. Although Plecoptera (stonefly) numbers were significantly lower in clus-3 than in clus-1a, the means for each of these two site groups were not significantly different from the mean for clus-2. The number of taxonomic groups was lowest for clus-3 and highest for clus-1b; there was no significant difference between clus-1a and clus-2 cluster means for this parameter. The Shannon-Wiener diversity was lowest for clus-3 and highest for clus-1a and clus-1b; the latter two were not significantly different from each other.

4.0 DISCUSSION

4.1 Community Descriptors

The results of the spring, summer, and fall invertebrate surveys of the North Saskatchewan River in 1982 showed important changes in the benthic invertebrate community in the river between Devon and Pakan Bridge. These changes can be attributed to an alteration of the quality of the water.

The most characteristic features of the changes in community parameters between Devon and Pakan Bridge are listed below:

1) The total invertebrate numbers per unit surface area increased downstream of the city. The highest number of specimens per unit surface area was recorded at the Rundle Footbridge right-bank site.
2) Shannon-Wiener diversity values were highest for the sites farthest upstream and downstream in the study section of the river. The lowest values were determined for the Rundle Footbridge right-bank site.
3) The distribution of numbers among major taxa showed two important changes. Sites upstream of Edmonton were characterized by an even distribution of numbers among taxa. The first change whereby oligochaetes, chironomids, and nematodes became dominant usually occurred between 50th Street Footbridge and Rundle Footbridge. The second change was an increase in mayfly, stonefly and caddisfly numbers which usually occurred between Sturgeon and Vinca Bridge, and

which marked the return to an even distribution of numbers among taxa. The return to an even distribution of numbers among taxa in the downstream part of the study section was interpreted as evidence of "recovery" from the impacts of effluent discharge in the greater Edmonton area.

4) There were slight and frequently inconsistent decreases in numbers of taxonomic groups within the city limits; the lowest value was recorded at Rundle Footbridge.

Although the changes described above were more pronounced for right-bank sites, they are also evident for left-bank sites. Most municipal effluents enter the river on the right bank.

The nature of the changes which occurred in the zoobenthic assemblies of the North Saskatchewan River in 1982 suggested that enrichment was the most significant impact. Enrichment contributes to increases in total numbers of organisms through total food enhancement; it could contribute to reduced diversity through temporary reductions in oxygen levels or through substrate fouling. There was no substantial evidence to indicate that the invertebrate community of the North Saskatchewan River was adversely impacted by the presence of toxic substances in effluents discharged into the river. In some river sections, toxic substances would have produced lower total numbers and even lower diversity, and possibly the total elimination of living organisms.

Temperature and food resources were the two factors most likely to limit the development of invertebrate populations in the

North Saskatchewan River. Although site-to-site temperature differences were neglegible on a given date (see Section 6.0, Part One), enrichment coming from point-source effluents resulted in substantial longitudinal differences in the quantity and quality of available food. On the other hand, seasonal temperature differences in the river were quite large, and these differences may have masked the effects of food abundance, especially at certain times of year.

Populations sampled in spring integrated the effects of winter conditions on the zoobenthos. In the winter, dissolved oxygen levels were adequate (see Section 7.0, Part One of this report), but invertebrate populations were unable to exploit fully the food available at certain sites, because low temperature reduced their metabolism and inhibited their growth and reproductive activity. Consequently, site-to-site differences detected in spring and attributable to the influence of point-source effluents were small.

Higher temperatures from spring through summer resulted in increased growth rates and reproductive activity of true benthic invertebrates. The emergence of adults of semi-aquatic insect species (e.g., Plecoptera, Ephemeroptera, Trichoptera, and Diptera) and their oviposition (egg-laying) represented the start of new generations which often had very high numbers at the outset. Population numbers in fall were largely a function of food availability during summer and fall and, therefore, differences between sites were maximal.

In general, the principal causes of the cultural eutrophication of rivers are effluents from municipal wastewater treatment plants and from industries, followed by runoff from agricultural and urban areas (Hynes 1960). These sources represent the addition of inorganic and organic nutrients to aquatic systems and contribute directly or indirectly to an abundant and renewable food supply for herbivorous and detritivorous organisms. Although increase in the amount of food available is in itself not detrimental, the oxidation of abundant organic material in water through both chemical and biological processes requires a large amount of dissolved oxygen, and this can contribute to the onset of anaerobic conditions in slow moving waters. Some invertebrate taxa have high oxygen requirements (e.g., Plecoptera, Ephemeroptera, and Trichoptera). The larvae of these insects are often designated as "clean water species". In contrast, "dirty water species" is a term used to describe Oligochaeta, Chironomidae and Nematoda, groups which are generally more tolerant of lower oxygen concentrations and which tend to be mainly detritivorous.

Hynes (1960) has described typical cases of severe organic pollution where the entire aquatic community was eliminated because of anaerobic conditions. In situations where only very low levels of oxygen remained in solution, tubificid worms and chironomid larvae were often the only invertebrates present. Hynes also described cases of mild organic pollution which occurred when biological treatment was efficient, or when dilution was great. In such cases, little more than a general increase in invertebrate population density was observed.

The invertebrate data collected in the North Saskatchewan River in 1982 did not resemble cases of severe organic pollution described as textbook examples in the literature. Instead, they were more similar to cases which Hynes cited as illustrative of mild organic contamination. In the North Saskatchewan River in 1982, the relatively high discharge rates and flow regulation (see Section 2.4, Part One) ensured high dilutions. Consequently, satisfactory levels of dissolved oxygen were maintained throughout the year. Flow regulation in the North Saskatchewan River has been cited as a major reason for improved dissolved oxygen conditions in recent years (Alberta Environment 1978, Bouthillier 1983, Paterson and Nursall 1975).

The impact of enrichment on the invertebrate community of the North Saskatchewan River was nonetheless distinct. In the upstream part of the study section, a relationship between changes in invertebrate community structure and point-source effluent discharges was established.

Low total invertebrate numbers, high H' values, and a fairly even distribution of numbers among taxa were features which characterized Devon and E.L. Smith, and were indicative of a virtually unimpacted invertebrate community and good water quality.

E. L. Smith was considered to be an unimpacted site, but the low percentage of clean water taxa (Plecoptera, Ephemeroptera, and Trichoptera) in the Fall suggested a slight perturbation. Although it was possible that these changes were due to human activities (such as the release of chlorinated effluents from the Devon Sewage Treatment Plant), it is more likely that they were caused by the activity of the huge corixid populations described above.

The first signs of enrichment were detected at Rossdale, primarily at the left-bank site. The community response was moderate: numbers were somewhat higher, but H' values remained unaffected; it was only in fall that oligochaete (tubificids and naidids) numbers increased appreciably. The left-bank site at Rossdale was the most upstream site in the study section where extensive filamentous algal growth was observed. The main potential sources of impact between E.L. Smith and Rossdale were storm sewers. The left-bank site at Rossdale was downstream of the Groat Bridge and Quesnell Bridge storm sewers, major sewers which drain the north-west part of the city. However, the possible existence of a number of small combined sewers in this section of the river is under investigation (see Section 2.10, Part One of this report).

Community changes were more apparent at the 50th Street Footbridge left-bank and right-bank sites, particularly in the fall. Higher total densities, a drop in diversity, and the dominance of oligochaetes distinguished these sites from upstream sites. Differences in invertebrate fauna composition between Rossdale and 50th Street were attributed to the influence of a number of major combined sewers in this part of the study section of the river. Combined sewers convey domestic sewage and surface runoff to the Gold Bar Wastewater Treatment Plant. During heavy rainfalls in 1982, the combined sewer system became overloaded and some raw sewage and surface runoff entered the North Saskatchewan River. These discharges were apparently more important in summer and fall than in winter or spring. Consequently, the impact from combined sewers on invertebrates was more evident in the fall sample set than in the spring sample set.

Because runoff episodes occur many times in most years, more or less permanent habitat alterations can be expected which, in turn, induce structural and functional changes in the benthic community. Urban runoff varies in its effect on aquatic biota, depending on its chemical and physical composition. At the Rossdale left-bank site and at both 50th Street sites, the effect of urban runoff was enrichment. It promoted the growth of filamentous algae and encouraged the development of a denser invertebrate community. Similar effects due to this type of enrichment have been documented elsewhere. For example, Pratt _et_ _al_. (1981) reported that the Greenfield urban runoff into the Green River (Massachusetts) resulted in a decrease in community diversity and a change in the taxonomic structure of the community, from one dominated by pollution (enrichment) sensitive forms to one dominated by pollution (enrichment) tolerant forms.

Although combined sewer effluents had a discernible influence on the water quality of the North Saskatchewan River, as evidenced by changes in the invertebrate community, it was downstream of the Gold Bar Wastewater Treatment Plant that the greatest changes in the invertebrate community occurred. The site most affected by the discharge from this plant was the right-bank site at Rundle Footbridge which was located immediately downstream of the plant outfall. The most remarkable change in the community at this site was the dramatic increase in oligochaete numbers, particularly for the family Naididae. With few exceptions, naidids feed on bacteria, detritus, and algae (Learner *et al*. 1978), and the main factors determining their distribution and abundance are the nature of the substrate, the presence and kind of vegetation, and the availability of oxygen. The response of naidids may vary with the types of pollutants entering a river. In general, however, the organic enrichment of rivers with stony substrates results in considerable naidid population increases. The high numbers of naidids (27,000 individuals per sample) recorded for the right-bank site at Rundle Footbridge were similar to those reported by Szczesny (1974) for a population of *Nais elinguis* in the Polish river Kryniczanka downstream of a sewage outfall. *Nais cummunis*/*variabilis*, and *Chaetogaster diaphanus* are also often observed in association with organic enrichment (Learner 1979). These two species, together with *N. elinguis*, dominated the naidid species association at the Rundle Footbridge right-bank site. There is little doubt that the high naidid numbers in the well aerated gravel riffles at Rundle Footbridge were induced by enrichment from the Gold Bar Wastewater Treatment Plant effluent.

Naidids are an important food source for predatory members of the benthic community (Learner *et al*. 1978) and represent an important pathway for energy transfer to higher trophic levels. Although naidids may be common in natural habitats, they are often also found in large numbers in sewage filter beds where they are believed to play a considerable role in the process of sewage breakdown (Learner 1979). It is quite possible that huge naidid populations like those which occurred downstream of the Gold Bar Wastewater Treatment Plant contributed greatly to the purification of the river water.

The magnitude of the naidid population at the Rundle Footbridge right-bank site resulted in a strongly skewed distribution of numbers among taxa and low diversity values. Marked declines in numbers of other taxonomic groups were only noted in the fall at this site. In spring and summer, thriving populations of mayflies, stoneflies, and caddisflies maintained fairly high numbers. This suggests that there was more stress on the invertebrate community in late summer and fall than at other times of the year. Higher water temperatures at that time probably intensified the impact of point-source effluents entering the river by contributing to higher metabolic rates and lower dissolved oxygen levels. Adverse effects on the invertebrate community would have been increased when primary treated sewage effluent was diverted into the river from the Gold Bar Wastewater Treatment Plant during rain-induced peak flows in the summer. The bypass of the secondary treatment process occurred on 32 days from June to October, 1982, 25 of these being in the months of July and August.

No differences in the invertebrate fauna were measured between the Rundle Footbridge left-bank site and the 50th Street Footbridge left-bank site. There were no additional point-source discharges between the two sites on this bank.

Spring and summer data from the right-bank site at Beverly Bridge were unexpected in the light of previously collected information for this location (Alberta Environment, unpublished data). The fauna showed little response to organic enrichment in 1982. Total numbers were much lower than at the Rundle Footbridge right-bank site, although the percentage of enrichment-tolerant taxa was high. As noted in Part One of this report (Section 3.0), lateral mixing in the North Saskatchewan River is poor; effluent plumes persist over relatively long distances, and the channels followed by these plumes change according to river discharge volumes. The Gold Bar Wastewater Treatment Plant effluent plume was probably confined to the central part of the river at Beverly Bridge during and prior to the spring and summer sampling in 1982 and thus had little influence on the site where invertebrates were sampled, as there were extensive shallows near the right bank at this location.

The changes which occurred in the community further downstream of Edmonton were neither as remarkable nor as consistent as those observed at the Rundle Footbridge right-bank site. The overall fauna composition changed little for sites from Clover Bar to Sturgeon. However, the population density for most taxonomic groups increased in downstream direction. Taxa most representative of this tendency were the mayflies _Tricorythodes_, _Heptagenia_, and unidentified Heptageniidae, the caddisflies _Psychomyia_, _Cheumatopsyche_, _Hydropsyche_, and unidentified Hydropsychidae, the stoneflies _Isoperla_ and _Alloperla_, and the mollusk _Ferrissia_. These taxa commonly occur in fairly eutrophic environments. Their food consists mainly of fine particulate organic matter (Merritt and Cummins 1979) and they are known to have relatively wide tolerances to a variety of chemicals. For example, Roback (1962) reported the occurrence of Hydropsychidae in waters with wide ranges in pH, turbidity, hardness, chloride, oxygen and nutrient concentration; Wiggins (1977) considered _Cheumatopsyche_ to be a genus tolerant of organic enrichment. Therefore, the consistent pattern of population increase among invertebrates downstream of Edmonton is primarily a response to organic enrichment.

The zoobenthic data collected in 1982 were not indicative of concentrations of toxic substances coming from municipal or industrial effluents. This study was not designed to identify specific or localized impacts from individual effluents to the river, but rather to characterize the integrated impact on water quality of all effluents to a section of the river. It is likely that municipal and industrial discharges downstream of Edmonton delay "recovery" of the fauna in the North Saskatchewan River by contributing additional enrichment. As discussed earlier, recovery implies the return to a community structure comparable to that of the unimpacted river.

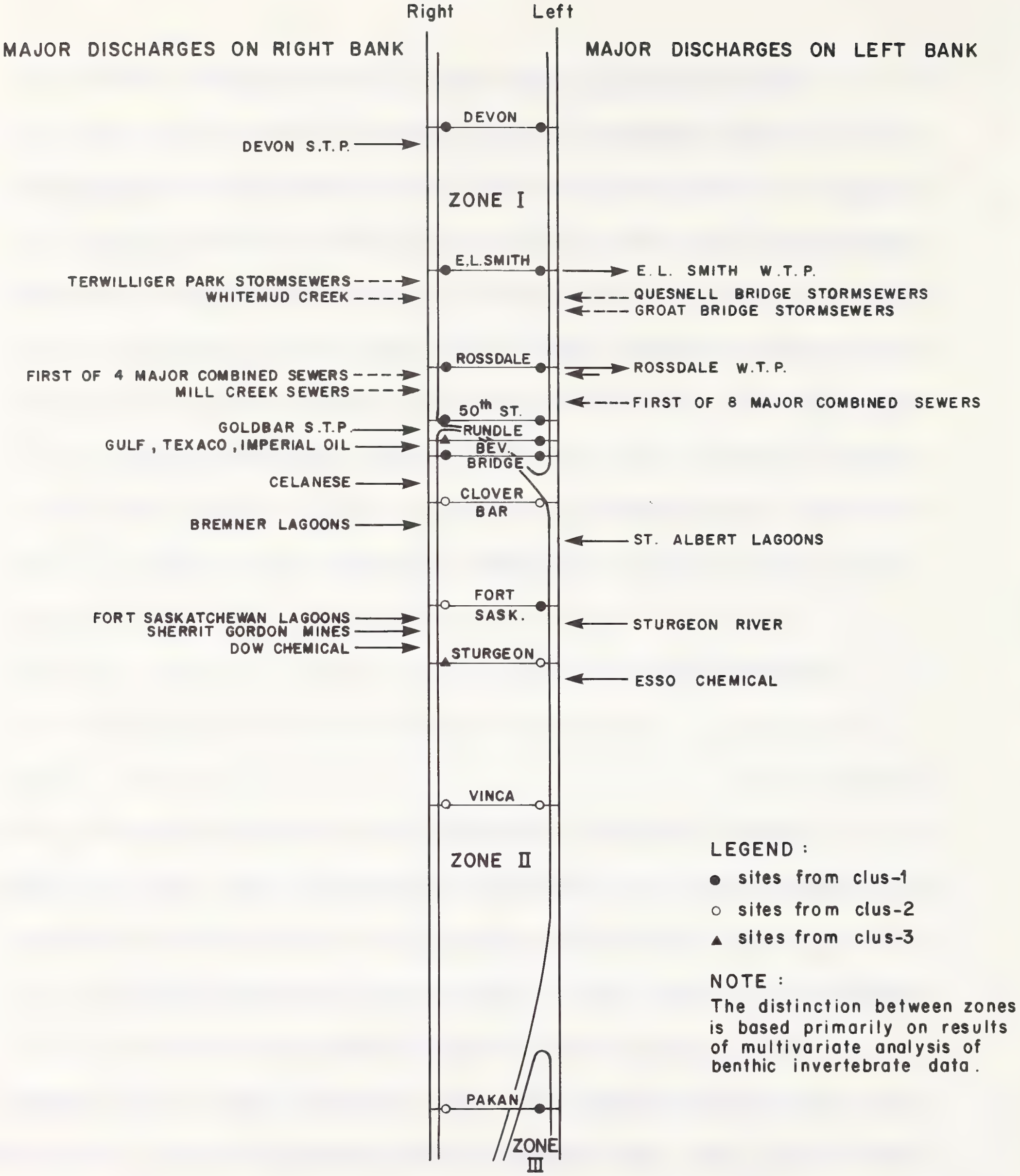
The invertebrate communities at Vinca Bridge and Pakan Bridge, the two locations furthest downstream in the study section of the river, showed consistent signs of recovery. The distribution of numbers among major taxa and the values for the Shannon-Wiener diversity index were comparable to those observed at Devon. However, total numbers were much higher. The invertebrate community characteristics indicated that the river water at Pakan Bridge had regained a level of quality satisfactory to the requirements of a diversity of invertebrates, but they also showed clearly that the river at Pakan Bridge was much more eutrophic than at Devon.

4.2 Multivariate Analyses

Spring and Fall

Figures 13 and 14 synthesize the information provided by the multivariate analyses of invertebrate spring and fall data. The three zones which are shown in these figures correspond to the site groups identified by cluster analysis and principal component analyses.

Zone I groups sites which were unaffected by major point-source effluents and which had unimpacted benthic invertebrate communities. This zone extended further downstream in the spring than in the fall. Sites which belonged to Zone I in the spring but not in the fall were downstream of major storm and combined sewer outfalls. The quality of spring runoff (ice melt) may have been different from that of summer runoff (rain) and the effects of spring runoff neither



NOTE:
The distinction between zones is based primarily on results of multivariate analysis of benthic invertebrate data.

FIGURE 13. SPRING 1982: SCHEMATIC PRESENTATION OF ZONES OF DIFFERENT WATER QUALITY IN THE NORTH SASKATCHEWAN RIVER

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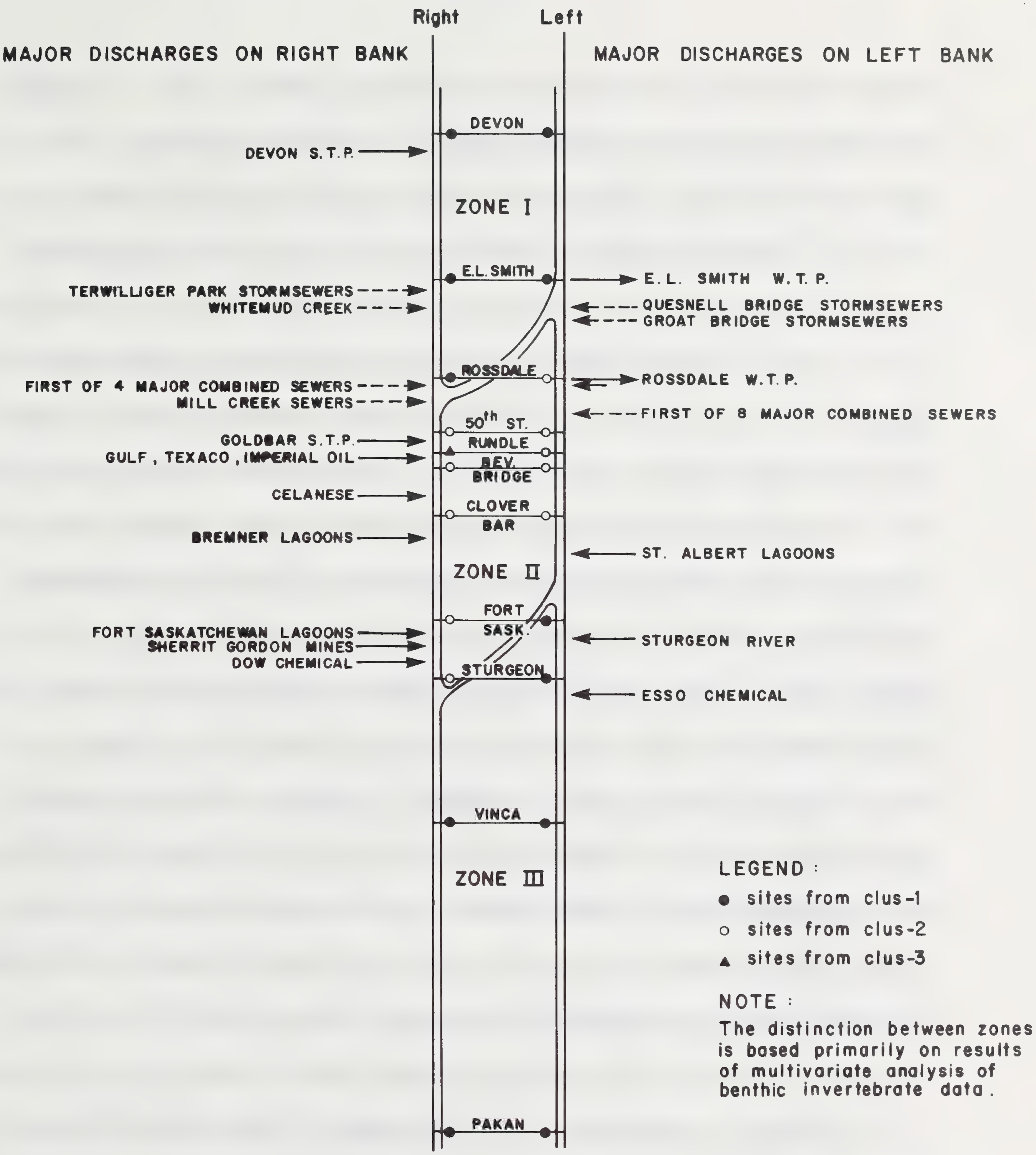

LEGEND :
- ● sites from clus-1
- ○ sites from clus-2
- ▲ sites from clus-3

NOTE :
The distinction between zones is based primarily on results of multivariate analysis of benthic invertebrate data.

FIGURE 14. FALL 1982 : SCHEMATIC PRESENTATION OF ZONES OF DIFFERENT WATER QUALITY IN THE NORTH SASKATCHEWAN RIVER

Alberta
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as persistent nor as perceptible as those of summer runoff. Mention was made earlier of the greater impact of combined sewers in the fall than in the spring. This was verified by cluster analysis and principal component analysis, which grouped sites affected by major combined sewers with other impacted sites in fall, but not in spring.

Zone II groups sites which were downstream of major municipal and industrial facilities. The invertebrate community clearly showed signs of impact at all of these sites. Multivariate analysis verified that two sites, Rundle Footbridge right-bank in both seasons and Sturgeon right-bank in spring only, had very different invertebrate communities and were more severely impacted than other sites. In spring, Zone II included two sites, Beverly Bridge right-bank and Fort Saskatchewan left-bank, which were grouped within Zone I sites according to cluster analyses. However, sampling problems, due to main channel shift at Beverly Bridge and to the influence of variable mixing patterns at Fort Saskatchewan, were suspected and these two sites probably belong in Zone II. Impacts from point-source effluents extended further downstream in the spring than in the fall. The reasons for this are discussed in greater detail below.

Zone III represents a recovery zone. The invertebrate communities at these sites showed many similarities to those of Zone I, the most important difference being the higher invertebrate densities at sites in Zone III. As a reflection of the remnant effects of winter conditions, the recovery zone began further downstream in the spring than in the fall. The reasons for this will also be discussed below.

Summer

Summer samples were collected about one month after the spring peak discharges, which were exceptionally high in 1982. This event must have been a major source of disturbance to the invertebrates. Waters (1972) has shown that changes in flow rates result in changes in drift rates. Taxa respond differently to this type of short-term disturbance; some are eliminated entirely, whereas others persist (Patrick 1970). Organisms which are washed from one area may become temporary or permanent residents of an area downstream, while they are themselves replaced by other organisms drifting from upstream. In this way, seasonal peak flows or floods can have a "homogenizing" effect on benthic invertebrate composition. Crossman _et_ _al_. (1974) came to a similar conclusion in their study of the Clench River in Virginia, where only minor site-to-site differences were detected after a flood event. Prior to the flood, however, a distinct clustering of sites, based on the taxonomic composition of the zoobenthos, could be related to the impact of point-source discharges. These authors concluded that floods have a homogenizing effect on the benthic invertebrate community. The situation in the North Saskatchewan River in 1982 was comparable, because no site clustering occurred after the late-spring peak discharges, even though there were definite patterns in the spring and fall data. As in the Clench River study, a marked increase in flow rates may have induced a more uniform summer distribution of invertebrates among sites. The Sturgeon left-bank site was distinctly different from all other sites at this time (see Fig. 10), but this difference was probably due more to substrate differences at this site or to drift from the Sturgeon River, than to water quality differences in the North Saskatchewan River.

4.3 Indications of a Seasonal Pattern in the Water Quality of the North Saskatchewan River

Despite the similarities between Figures 13 and 14, there were important differences in the zones which were indicative of water quality in the North Saskatchewan River in the spring and fall of 1982. Some of these differences (e.g., inclusion or exclusion of sites located below storm and combined sewers in Zone I) can be explained by qualitative differences in effluents discharged into the river. Other differences, such as the lengths of the impacted and recovery zones (Zone II and Zone III, respectively) in spring and fall, have causes other than effluent quality.

Most biological and chemical processes proceed more rapidly at high temperatures than at low temperatures. Therefore, in a well oxygenated river, biological and chemical degradation will be more efficient during the warm period of the year than in winter and early spring. Consequently, Zone II should be longer in the winter than in the summer. This alone could explain the difference in the length of Zone II in spring and in fall; spring invertebrate data were a cumulative reflection of water quality conditions during winter and early spring, whereas fall invertebrate data were a cumulative reflection of summer and early fall conditions. However, it is likely that river discharge had a strong influence on zone boundaries.

Except for the local runoff in spring, flows are usually low and steady in winter and early spring in the North Saskatchewan River. Late spring and early summer flow rates are usually higher and variable because of mountain runoff and storm events. If both phenomena coincide, as was the case in 1982, discharges can increase dramatically.

High discharges have a homogenizing effect on benthic invertebrate distribution and have a "flushing" or "cleansing" effect on the river as a whole. In terms of late-spring/early summer flushing effects, the fall picture can be thought of as the cumulative effect of 3 or 4 months of near optimal temperature and flow conditions. The spring picture can be considered to represent the cumulative effect of varying temperature and flow conditions over most of the year.

The river zone patterns for spring and fall may be regarded as indicative of a cyclic and dynamic phenomenon whereby the river is cleansed annually and is "soiled" gradually during the rest of the year by discharges from urban areas. The extent of the most impacted zone may vary from year to year and during the course of the year as a result of changes in flow rates, water temperatures, and overall effluent quality and quantity.

5.0 CONCLUSIONS

a) There were clear patterns of change in the benthic invertebrate associations of the North Saskatchewan River in 1982 between Devon and Pakan Bridges; these changes conformed with certain variations in water quality, particularly nutrient and organic enrichment.

b) The invertebrate responses downstream were typical of enrichment. Invertebrate populations responded to greater food availability by increasing in density. This was particularly evident in taxa such as Chironomidae, Nematoda, and Oligochaeta, which are tolerant of environmental stress. Lower Shannon-Wiener diversity values reflected changes in community composition.

c) The first indications of major density and compositional changes occurred in the section of the river which passes through the Edmonton urban area; they were more pronounced at right-bank sites, where the majority of point-source effluents enter the river.

d) The magnitude and nature of the effects of effluents entering downstream of the Fort Saskatchewan location were more difficult to determine because they were masked by the remnant effects of upstream effluents.

e) Stormsewer effluents were the first to have an enrichment effect on the river. However, their impact on the invertebrate community occurred only in the fall, not in spring. This suggested that surface runoff in spring (snowmelt) had a different quality than that in summer and fall (rain).

f) The effects of combined sewers, which discharged surface runoff and raw sewage to the river during periods of heavy rainfall, impacted the invertebrate community only in fall, not in spring.

g) The Gold Bar Wastewater Treatment Plant effluent was a continuous and major food source for invertebrates; it had the most consistent and demonstrable effect on invertebrates. The influence of the Gold Bar Wastewater Treatment Plant was evident a considerable distance downstream of the Edmonton city limits and it overshadowed the impacts of other effluents.

h) The fact that benthic invertebrates of nearly all taxa increased in numbers downstream of Edmonton indicated that industries in the Edmonton and Fort Saskatchewan area did not have an overall toxic impact on invertebrates but, instead, contributed to the eutrophication of the river.

i) The sites sampled comprised three main site groups which corresponded to three zones of water quality: an unimpacted zone upstream of Edmonton, an impacted zone downstream of effluents, and a recovery zone. The invertebrate associations in the recovery zone were rather similar to those in the unimpacted zone; however, the much higher numbers in the recovery zone indicated that the river was more eutrophic downstream of Edmonton. These zones were distinguished by cluster and principal component analyses.

j) Benthic invertebrate data indicated the existence of a cyclic and dynamic pattern of water quality in the river. The relative length of the impacted zone and of the recovery zone would be determined not only by effluent quality and quantity, but also by biological and chemical degradation processes and flow rates. The length of the impacted zone would be shortest during the summer, following the flushing effect of spring peak discharges and a period of optimum conditions for degradation processes. As water temperatures drop in the fall and flow rates decrease, the impacted zone extends gradually further downstream to become longest in the winter.

k) Although the zoobenthos alone does not present a conclusive argument for the judging of water quality, seasonal and spatial patterns were clear and statistically significant. They identify times and locations where physical and chemical studies should be concentrated.

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APPENDIX

APPENDIX I: Scientific names of benthic invertebrates and their common equivalents frequently used in this report.

APPENDIX I. Scientific names of benthic invertebrates and their common equivalent(s) frequently used in this report.

Scientific Names	Common Names
	'coelenterates'
Coelenterata	sac animals, such as hydras
	'crustaceans'
Amphipoda	scuds, sometimes "freshwater shrimps"
Arachnida (Acari and Aranea)	spiderlike animals (mites and spiders)
	'worms'
Turbellaria	flatworms
Hirudinea	leeches, "blood suckers"
Oligochaeta	bristle worms
Nematoda	round worms
	'insects'
Diptera	two-winged flies such as midges, mosquitoes no-see-ums, black-, deer-, horse-, and crane-flies
Lepidoptera	butterflies, moths
Odonata	dragonflies and damselflies
Collembola	springtails
Ephemeroptera	mayflies
Trichoptera	caddisflies
Plecoptera	stoneflies
Corixidae	water-boatmen
Coleoptera	beetles
	'mollusks'
Mollusca	clams and snails